BroadMX Architecture

Key architectural features for communications performance

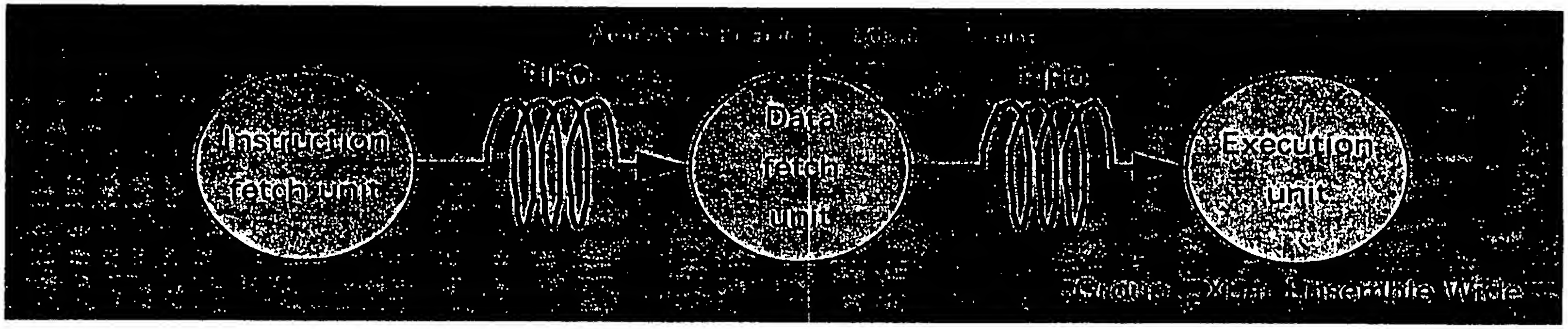
Major Operation Codes

31 — 24	23 — 0
major	other
8	24

	Front End: Access				Back End: Execution			
	Address	Branch	Load	Store	Group	Xbar	Ensemble	Wide
MAJOR	0	32	64	96	128	160	192	224
0	[illegible]	[illegible]	L16L	S16L	[illegible]	XDEPOSIT	EMULX	WMULMATXL
1	[illegible]	[illegible]	L16B	S16B	GADD		EMULXB	WMULMATXB
2	AADD	[illegible]	L16AL	S16AL	GADDO		[illegible]	[illegible]
3	AADDUO	[illegible]	L16AB	S16AB	GADDUO		[illegible]	[illegible]
4	[illegible]	[illegible]	L32L	S32L	[illegible]	XDEPOSITU	EMULADDX	WMULMATXML
5	ASUB	[illegible]	L32B	S32B	GSUB		[illegible]	WMULMATXMB
6	ASUBO	[illegible]	L32AL	S32AL	GSUBO		[illegible]	WMULMATXGL
7	ASUBUO	[illegible]	L32AB	S32AB	GSUBUO		[illegible]	WMULMATXGB
8	[illegible]	[illegible]	L64L	S64L	GSETE	XWITHDRAW	ECONXL	[illegible]
9	ASETNE	[illegible]	L64B	S64B	GSETNE		ECONXB	[illegible]
10	ASETANDE	[illegible]	L64AL	S64AL	GSETANDE		[illegible]	[illegible]
11	ASETANDNE	[illegible]	L64AB	S64AB	GSETANDNE		ECONXUB	[illegible]
12	ASETL	[illegible]	L128L	S128L	GSETL	XWITHDRAWU	ECONXML	[illegible]
13	ASETGE	[illegible]	L128B	S128B	GSETGE		ECONXMB	[illegible]
14	[illegible]	[illegible]	L128AL	S128AL	GSETLU		[illegible]	[illegible]
15	ASETGEU	[illegible]	L128AB	S128AB	GSETGEU		[illegible]	[illegible]
16	[illegible]	BE	[illegible]	SAS64AL	GAND	XDEPOSITM	ESCALADDF16	[illegible]
17	ANAND	BNE	[illegible]	[illegible]	GNAND		ESCALADDF32	[illegible]
18	AOR	[illegible]	[illegible]	[illegible]	GOR		[illegible]	[illegible]
19	ANOR	[illegible]	[illegible]	[illegible]	GNOR		[illegible]	[illegible]
20	AXOR	[illegible]	[illegible]	SMS64AL	GXOR	XSWIZZLE	[illegible]	[illegible]
21	AMUX	[illegible]	[illegible]	SMS64AB	GMUX		[illegible]	[illegible]
22	[illegible]	[illegible]	[illegible]	[illegible]	GBOOLEAN		[illegible]	[illegible]
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		EEXTRACT	[illegible]
24	[illegible]	[illegible]	[illegible]	[illegible]	GCOPYI	XEXTRACT	[illegible]	[illegible]
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	WTABLEL
27	[illegible]	[illegible]	[illegible]	[illegible]	G8	[illegible]	[illegible]	WTABLEB
28	[illegible]	[illegible]	L8	S8	G16	XSHUFFLE	[illegible]	WSWITCHL
29	[illegible]	[illegible]	[illegible]	[illegible]	G32	XSHIFTI	E32	WSWITCHB
30	[illegible]	BLINK	[illegible]	[illegible]	G64	XSHIFT	E64	WMINORL
31	AMINOR	BMINOR	LMINOR	SMINOR	G128		E128	WMINORB

SuperSpring

- Decouples Access from Execution



MicroUnity

SuperThread

- Simultaneous Multithreading
- Expensive resources ($, X, E, T) shared among threads
  - improves utilization of resources
- Cheap resources (A, B, L, S) dedicated per thread
  - keeps branch latency low
  - enables multiple front-end architectures

MicroUnity

SuperWide

- Memory operand in read-only cache
- Full width register operands
- Full width register result
- Peak utilization of data path bandwidth and flexibility

Instruction Formats

31 24	23 0
major	imm
8	24

31 24	23 18	17 0
major	rd	imm
8	6	18

31 24	23 18	17 12	11 0
major	rd	rc	imm
8	6	6	12

31 24	23 18	17 12	11 6	5 0
major	rd	rc	rb	minor
8	6	6	6	6

31 24	23 18	17 12	11 6	5 0
major	rd	rc	rb	ra
8	6	6	6	6

Address Instructions

- Fixed-point operations over 64-bit addresses
- Add, Subtract, Set-conditional
- Boolean: 2-operand, MUX
- Shift immediate
- Shift left immediate add
- Compare

Load, Store, Sync Instructions

- Attributes
  - type: signed, <u>U</u>nsigned
  - size: <u>8</u>, <u>16</u>, <u>32</u>, <u>64</u>, <u>128</u>
  - alignment: <u>A</u>ligned, unaligned
  - ordering: <u>L</u>ittle-endian, <u>B</u>ig-endian
- Synchronization: <u>64</u> <u>A</u>
  - add-, compare-, mux-swap; mux
- Addressing forms
  - register + shifted immediate
  - register + shifted register

Synchronization

- Aligned octlet operations
  - Add-Swap
    - load mem->reg, add reg+mem->mem
  - Compare-Swap
    - load mem->reg, compare reg<->reg, if equal, store reg->mem
  - Mux-Swap
    - load mem->reg, mux:mask,reg,mem->mem
  - Mux
    - load mem, mux:mask,reg,mem->mem

MicroUnity

Branch Instructions

- B.LINK, B.LINK.I — Procedure call
- B.I — Unconditional
- B — Procedure return, switch
- B.DOWN — Gateway return
- B.BACK — Exception return
- B.HALT — Interrupt wait
- B.BARRIER — Instruction-fetch wait
- Branch conditional
- Branch hint
- Branch gateway

MicroUnity

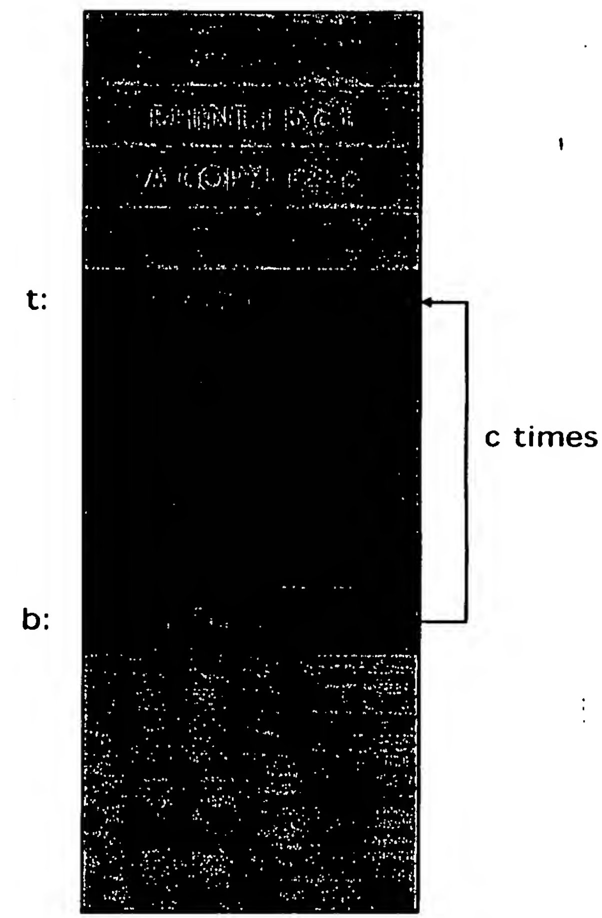
Branch Conditional

- Floating-point: F16 F32 F64 F128
  - B.E.F, B.LG.F, B.L.F, B.GE.F
- Homogeneous Coordinates: 4xF32
  - B.V.F, B.NV.F, B.I.F, B.NI.F
  - Visible: line within viewing cube
  - Invisible: line outside viewing cube
- Fixed-point: 128 bits
  - B.E, B.NE, B.L, B.GE, B.L.U, B.GE.U
  - B.AND.E.Z, B.AND.NE.Z
  - B.E.Z, B.NE.Z, B.L.Z, B.G.Z, B.LE.Z, B.GE.Z

Branch Hint

- Hints for loops, switches, methods
- Fully interruptible

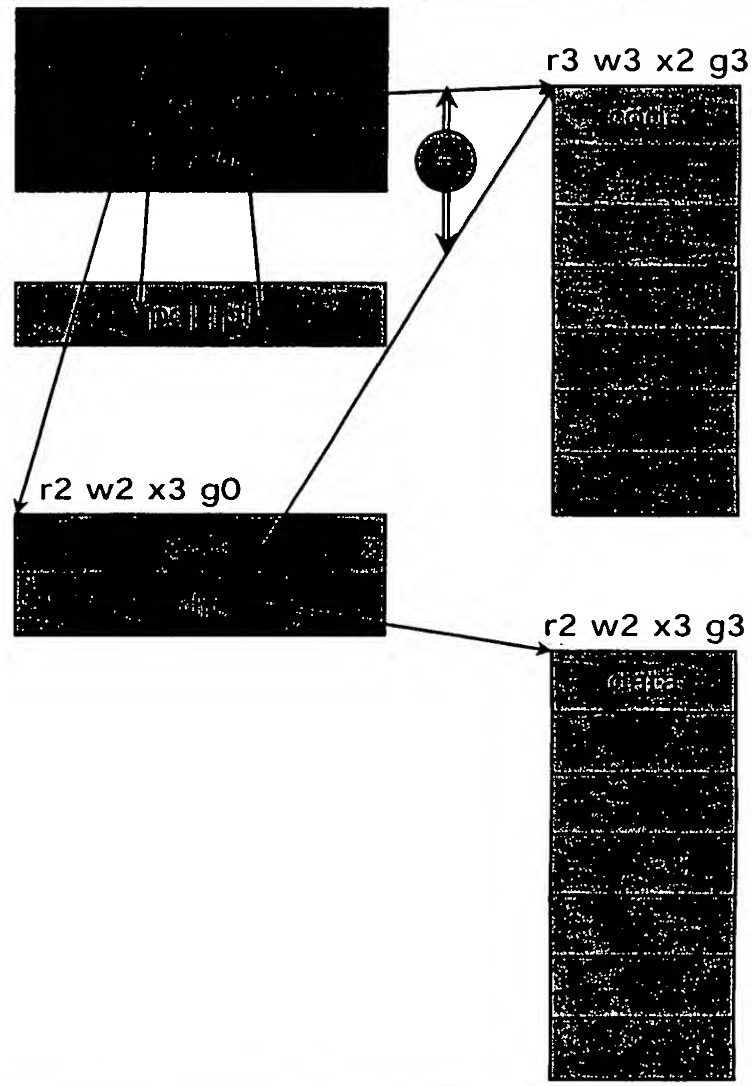
- B.HINT.I b,c,t
- B.HINT b,c,rd
  - Branch at **b** is likely **c** times, to **t/rd**, then is not likely.



Branch Gateway

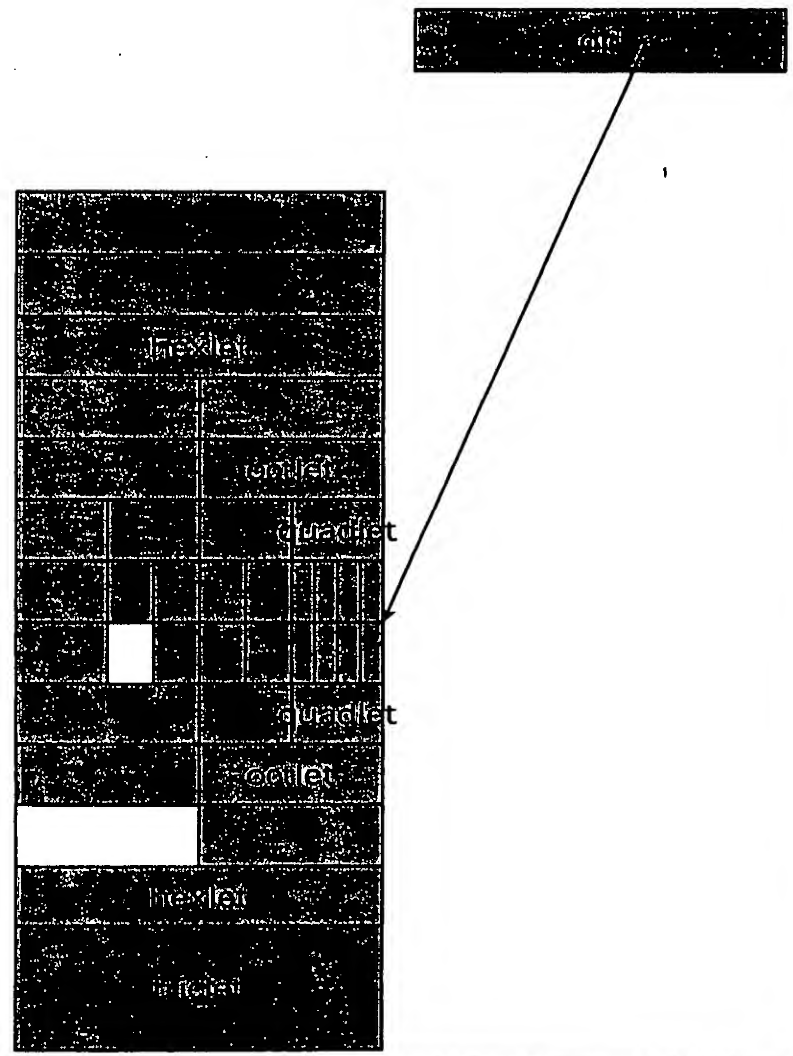
- **Gateway**
  - level 0 to 2
  - secure entry
  - data pointer
  - stack pointer
- **Code**
  - LI64LA dp=dp,off
  - LI64LA lp=dp,0
  - B.GATE (lp=dp,lp)

  - LI64LA dp=dp,8
  - SI64LA sp,dp,off
  - LI64LA sp=dp,off



Data pointer

- Memory pool for literals, statics
- procedures may share pool
- items sorted by size
- smallest items near dp
- All items aligned to size



MicroUnity

Procedure call conventions

- Compatible with dynamic linking
- Register 63 (sp) is stack pointer
- Stack space allocated for parameters by caller
- Up to 8 parameters passed in registers 2-9
- Register 0 (lp) loaded with procedure address
- Register 1 (dp) loaded with data pointer
- To enter: BLINK lp=lp
- Register 2 contains return value
- To return: B lp

Procedure Call Structure

- Caller (non-leaf):

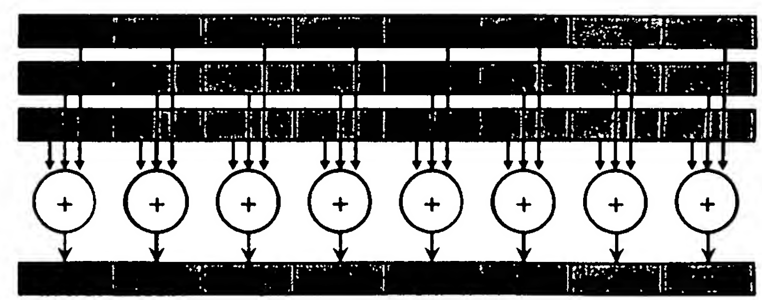
```
ADDI      sp,-size       # allocate stack space
SI64LA    lp,sp,off      # save link pointer
SI64LA    dp,sp,off      # save data pointer
  ...                    # use data pointer
B.LINK.I  callee         # call procedure with shared dp
  ...                    # use data pointer
LI64LA    lp=dp,off      # load callee code address
LI64LA    dp=dp,off      # load callee data pointer
B.LINK    lp             # call procedure
  ...                    # data pointer not available
LI64LA    dp=sp,off      # reload data pointer
  ...                    # use data pointer
LI64LA    lp,sp,off      # reload link pointer
ADDI      sp,size        # deallocate stack space
B         lp             # return to caller
```

- Callee (leaf):

```
  ...                    # args in reg, use data pointer
B         0              # return to caller
```

Group Instructions

- Fixed-point operations over 128-bit operands with 8..128 bit symbols
- Add, Subtract, Set-conditional
- 3-operand Add/Subtract
- Add/Subtract Halve, Limiting
- Boolean: 3-operand, MUX
- Shift left immediate add
- Compare



MicroUnity

Group triple operand

- Reduces latency for common arithmetic operations
- Group triple add/subtract
  - $rd_{128} = rd_{128} \pm rc_{128} + rb_{128}$
  - 8-128 bit symbols
- Group shift 1-4 and add/subtract
  - matches load/store with shifted index
- Group triple boolean immediate
  - $rd_i = f(rd_i, rc_i, rb_i)$, $i=0..127$
  - 8 immediate bits specify f

Typical boolean functions

■ dcb	10000000	128
■ dc|b	11101010	234
■ d|c|b	11111110	254
■ d?c:b	11001010	202
■ d^c^b	10010110	150

MicroUnity

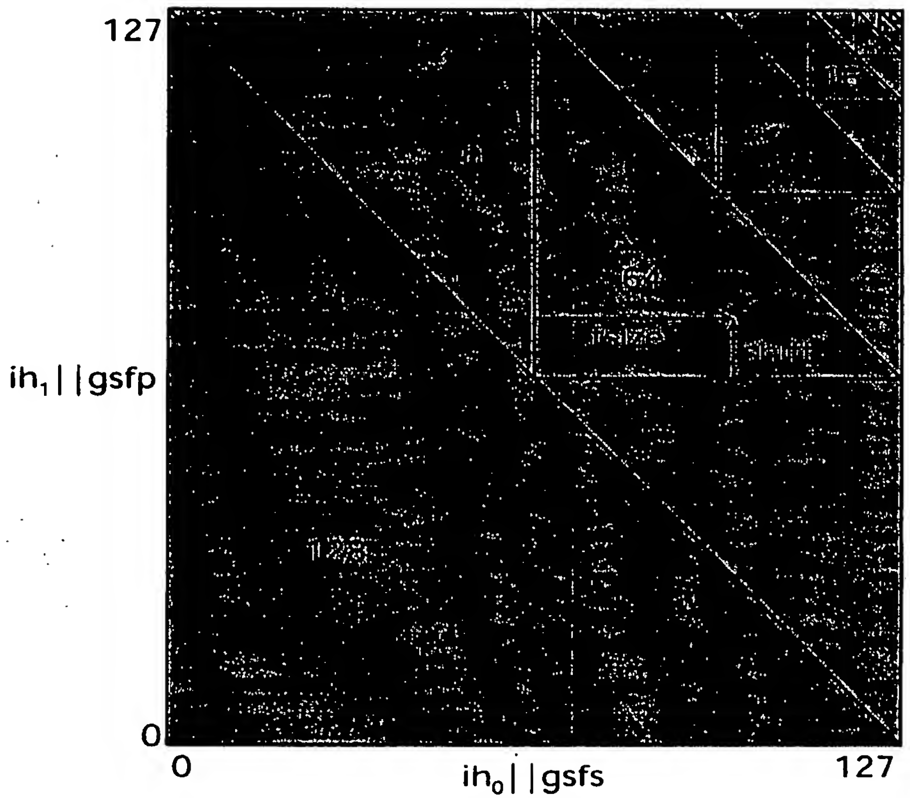
X: Crossbar Instructions

- Deposit, Withdraw
- Extract, Expand, Compress
- Swizzle, Select, Shuffle
- Shift
- Shift-Merge
- Rotate

- Wide Switch

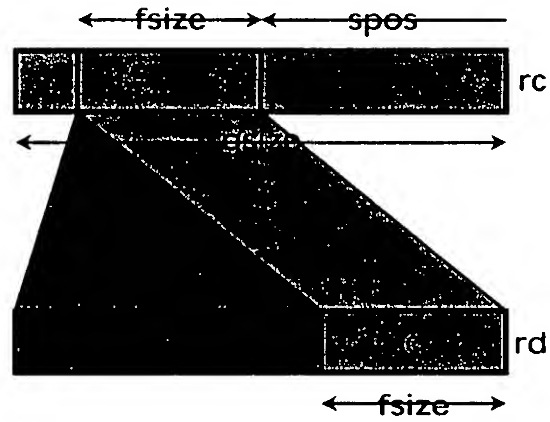
Crossbar field

- fsize, shift (or spos/dpos)

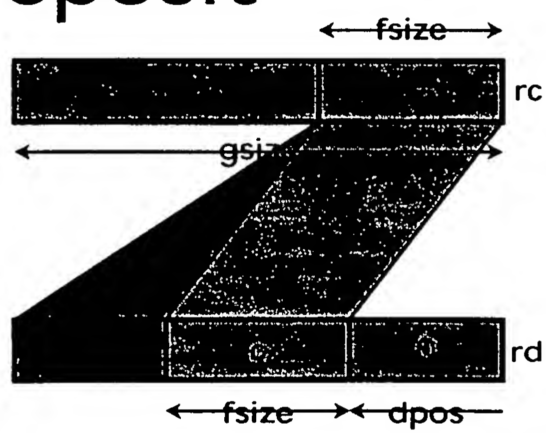


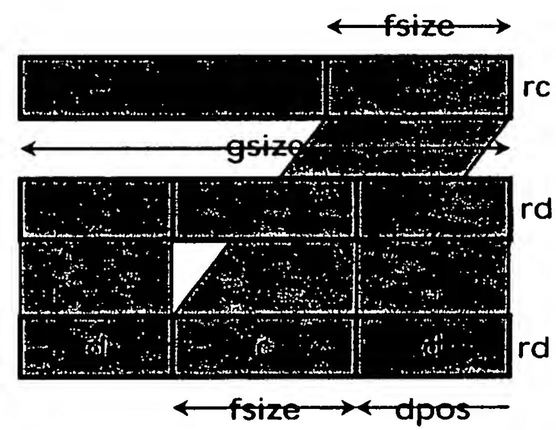
Crossbar field

- withdraw



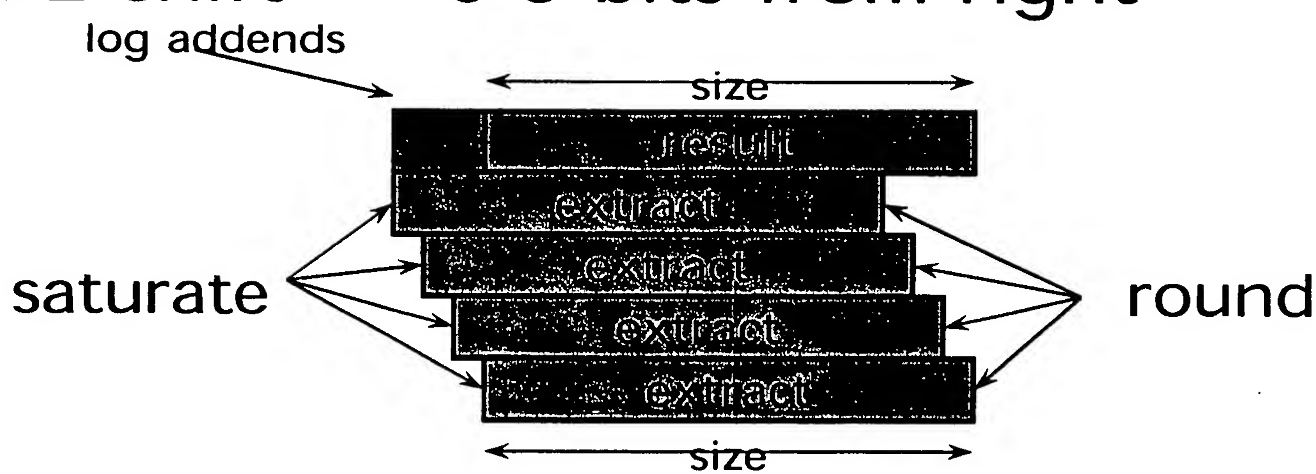
- deposit





Crossbar extract control

- immediate control fields
  - 2 size 8, 16, 32, or 64 bits
  - 1 saturate signed, unsigned
  - 2 round floor, ceil, zero, even
  - 2 shift 0-3 bits from right



MicroUnity

Crossbar extract

- $rd_i = (ra_{128} \,||\, rb_{128})_{f(rc_{32},i)}$, $i=0..127$
- extract w/register operand control
- register specifies:
  - 8 fsize field size
  - 8 dpos destination position
  - 9 gssp group size and source position
  - 1 s signed vs unsigned
  - 1 n (real vs complex)
  - 1 m extract vs merge (or mixed sign)
  - 1 l saturation vs truncation
  - 2 rnd rounding

Crossbar extract control

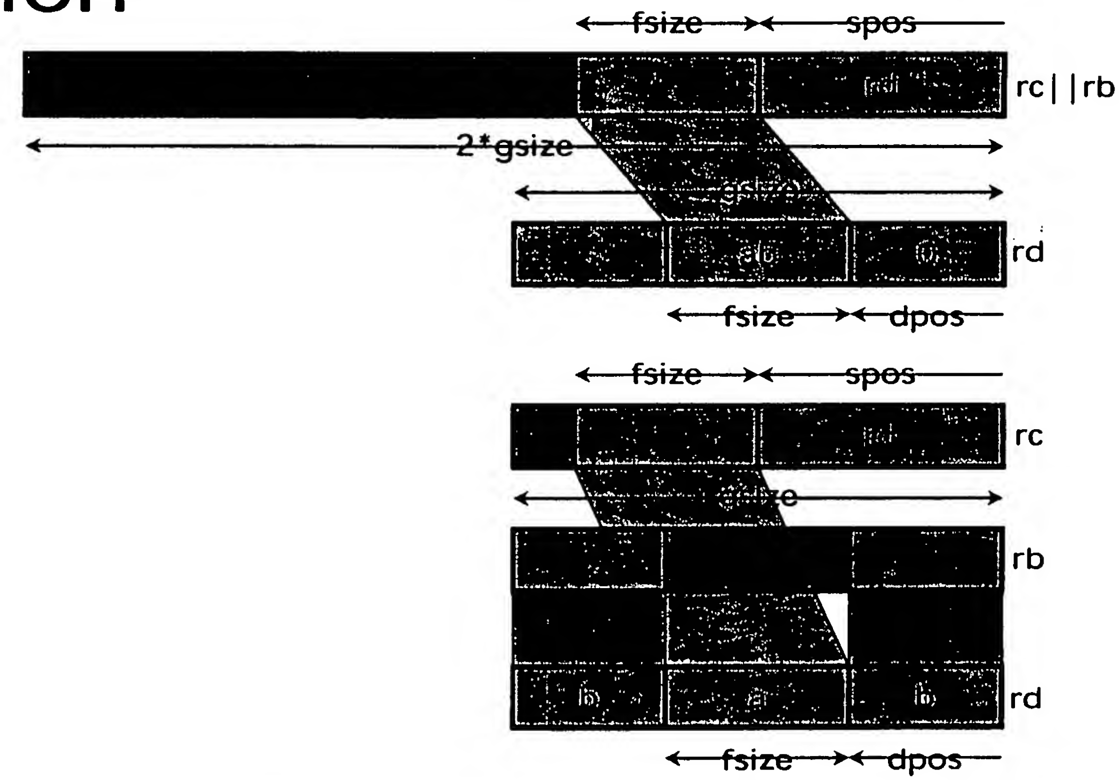
- layout

31–24	23–16	15	14	13	12	11	10–9	8–0	
fsize	dpos	x	s	n	m	l	rnd	gssp	rc
8	8	1	1	1	1	1	2	9	

- function

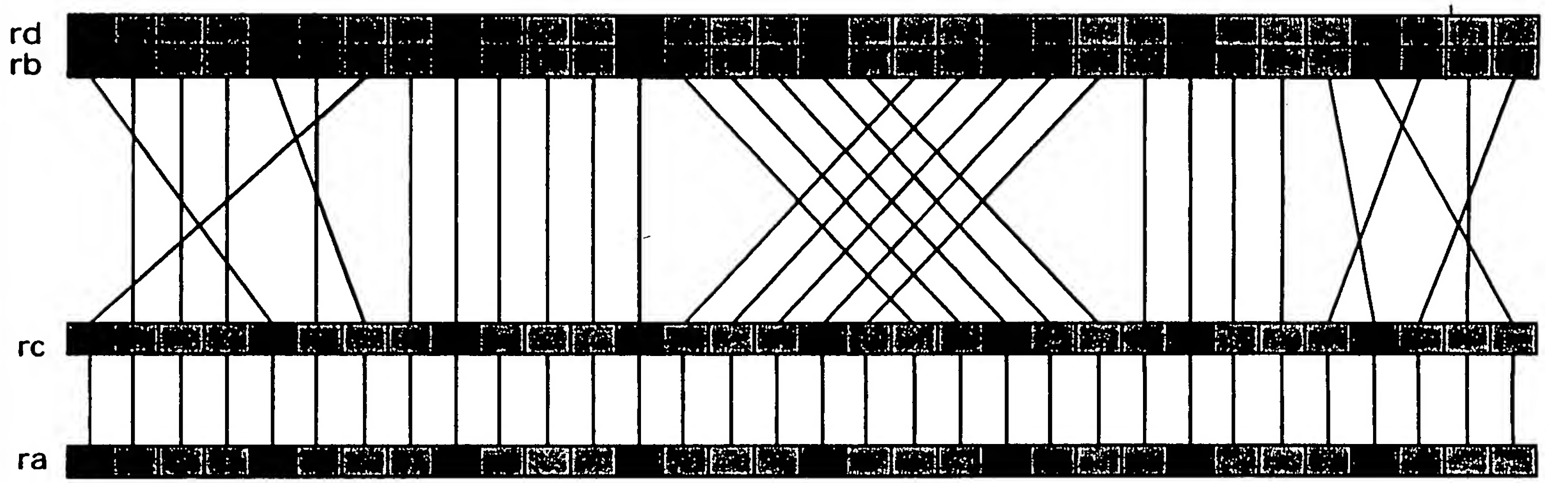
m=0

m=1



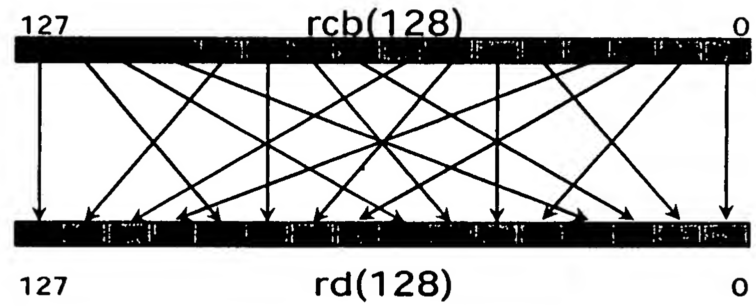
Crossbar Select bytes

- X.SELECT.8 ra=rc,rd,rb



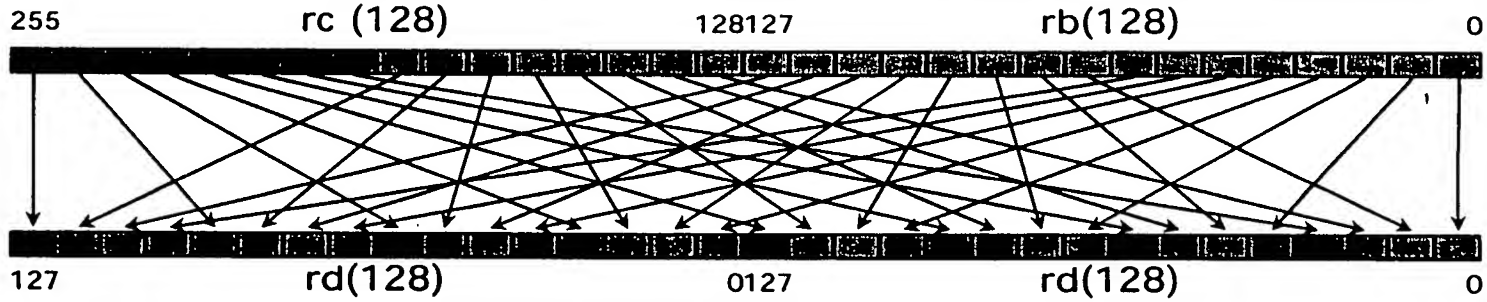
4-way shuffle bytes within hexlet

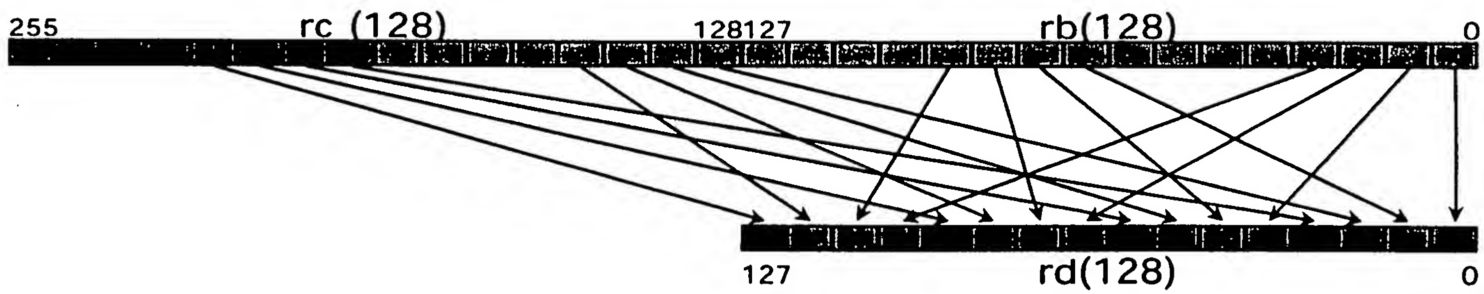
- XSHUFFLEI.128 rd=rcb,8,4



4-way shuffle bytes within triclet

- XSHUFFLEI.128 rd=rc,rb,8,4





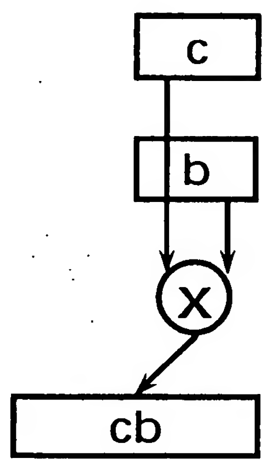
Ensemble Instructions

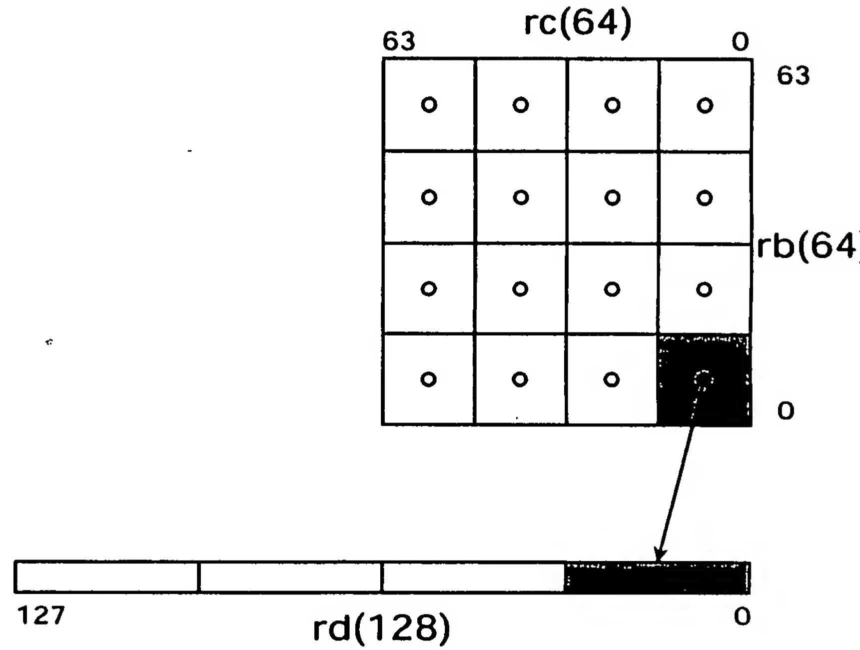
- Multiply
  - Fixed-point
    - size-doubling
    - extract
  - Floating-point
  - Complex
  - Polynomial
  - Galois Field

  - Convolve
  - Multiply-add
  - Scale-add
  - Multiply-sum
- Floating-point
  - Add, Subtract, Divide, Sum
  - Inflate, Deflate, Float, Sink
  - Reciprocal Estimate
  - Reciprocal Square Root Estimate
- Fixed-point
  - Sum
  - Log-most

Multiply

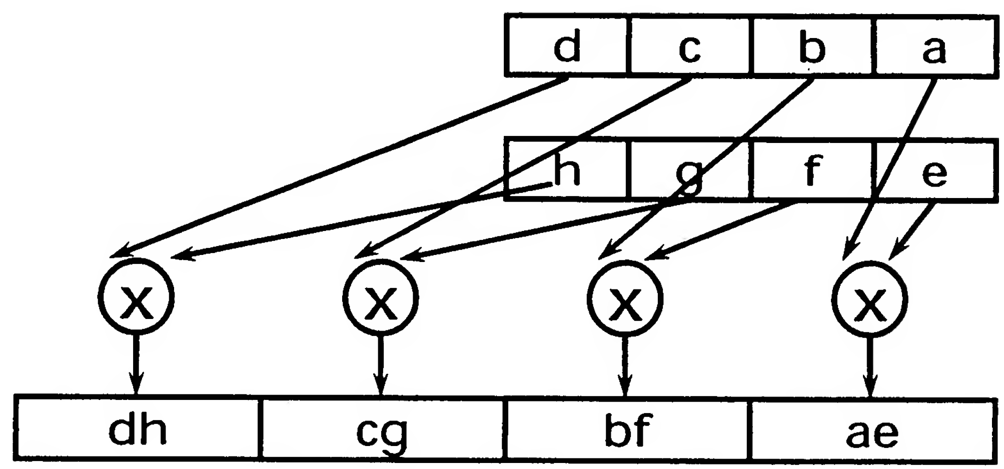
- $rd_{32} = rc_{16} * rb_{16}$





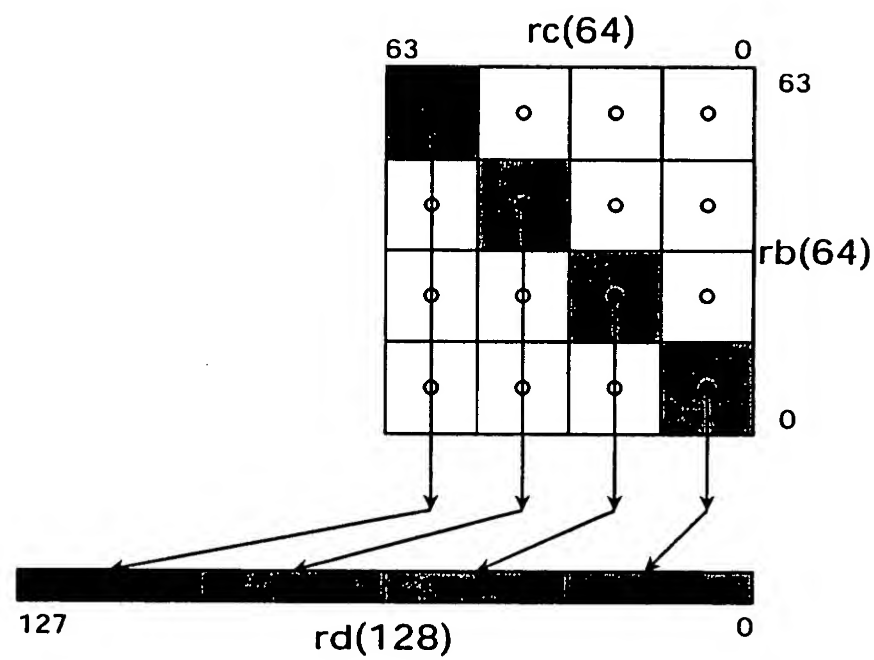
Ensemble multiply

- $rd_{128} = rc_{64} * rb_{64}$



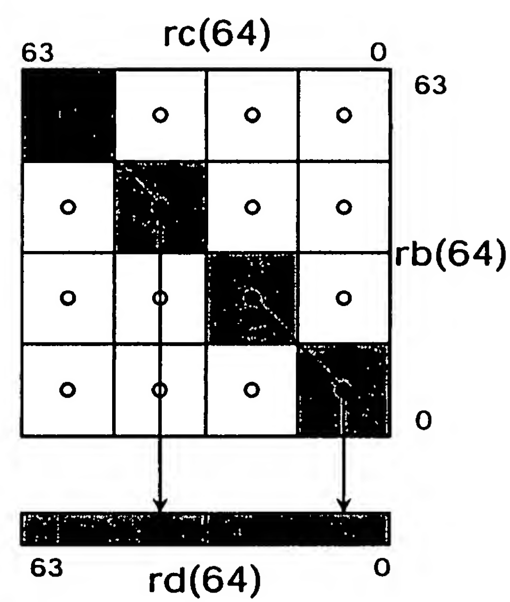
Ensemble multiply

- $rd_{128} = rc_{64} * rb_{64}$



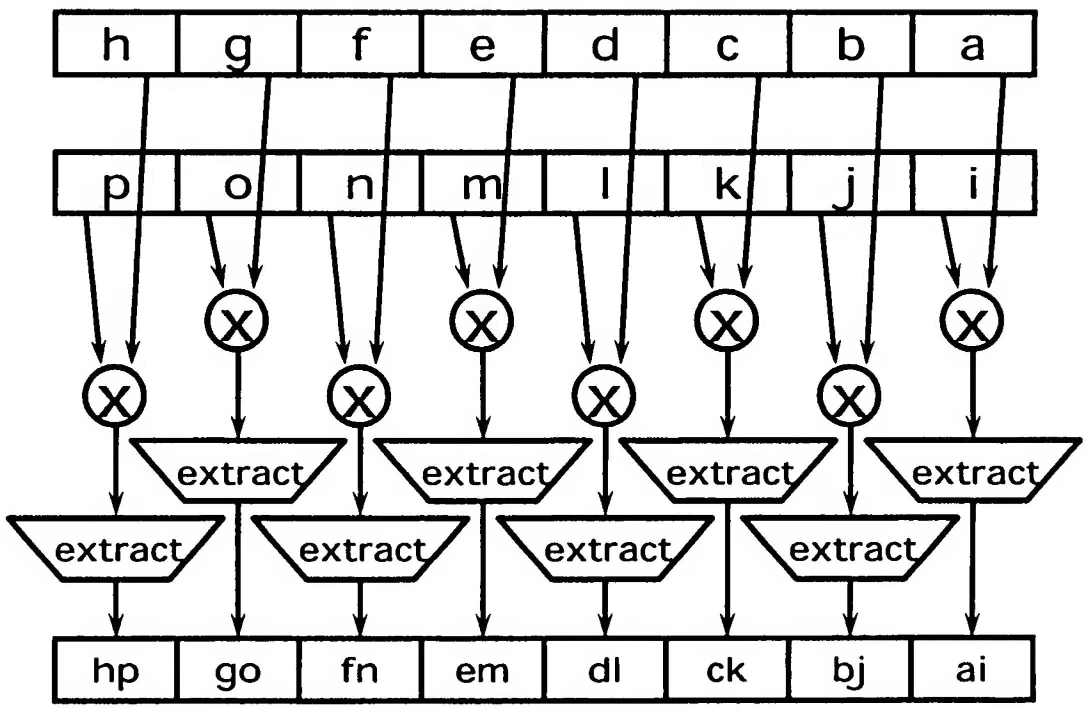
MMX PMADDWD

- $rd_{128} = rc_{64} * rb_{64}$



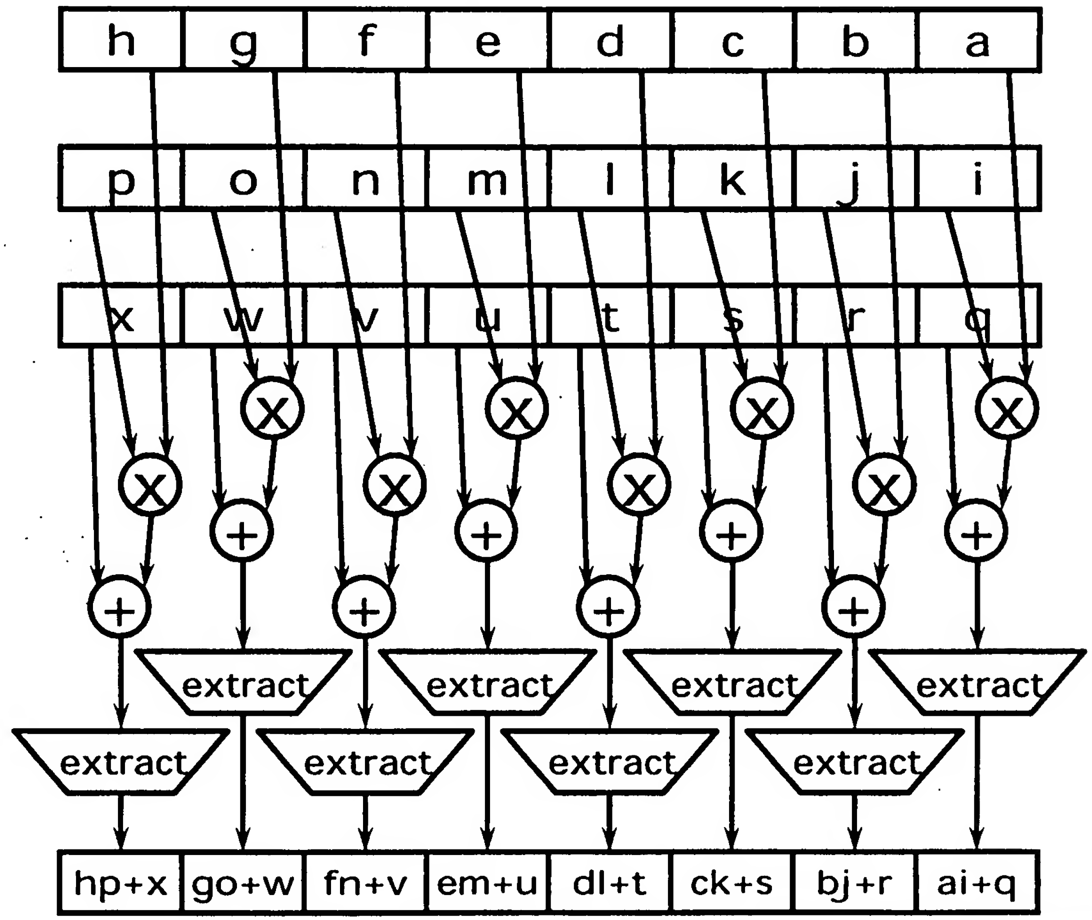
Ensemble multiply extract

- $rd_{128} = rc_{128} * rb_{128}$



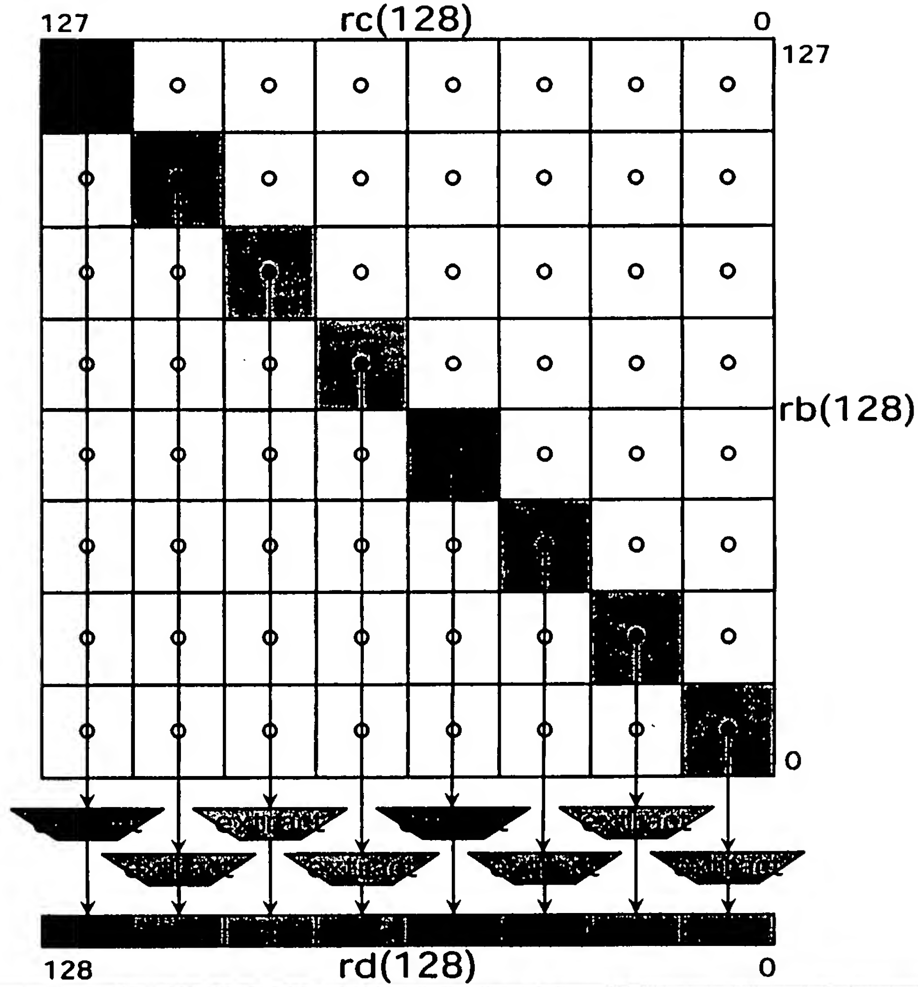
Ensemble multiply add extract

- $rd_{128} = rc_{128} * rb_{128} + rd_{128}$



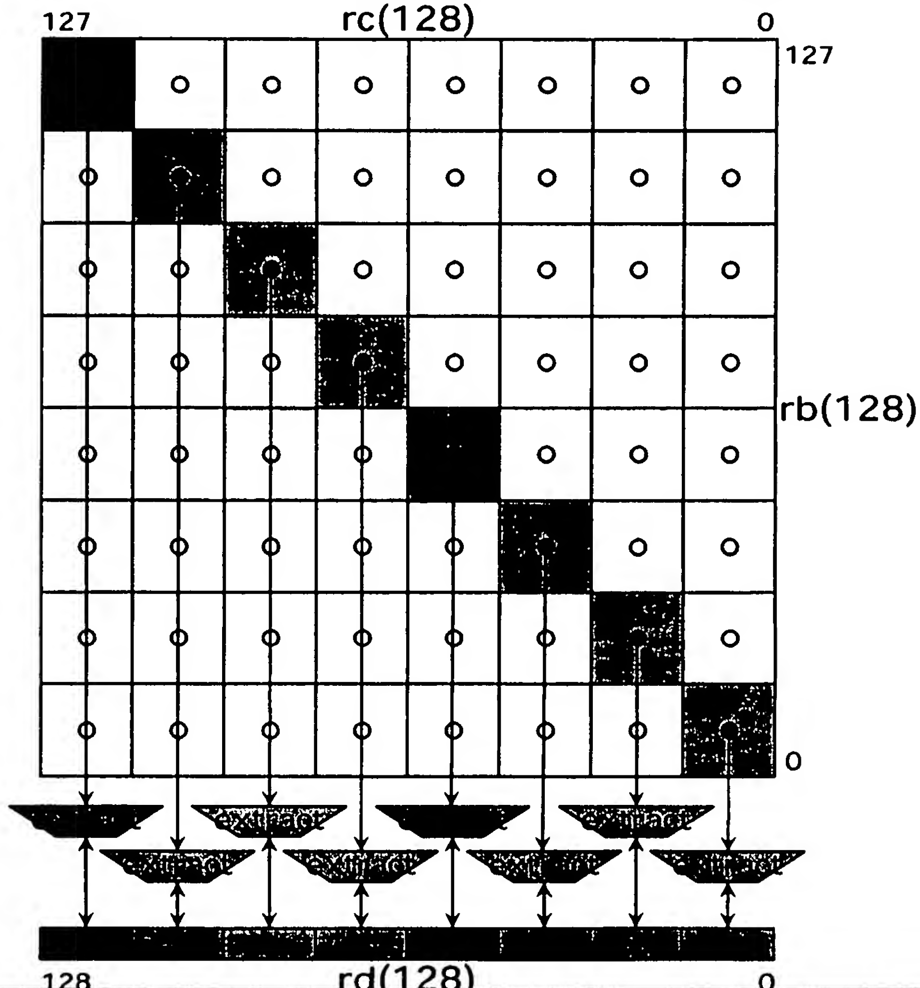
Ensemble multiply extract

- $rd_{128} = rc_{128} * rb_{128}$



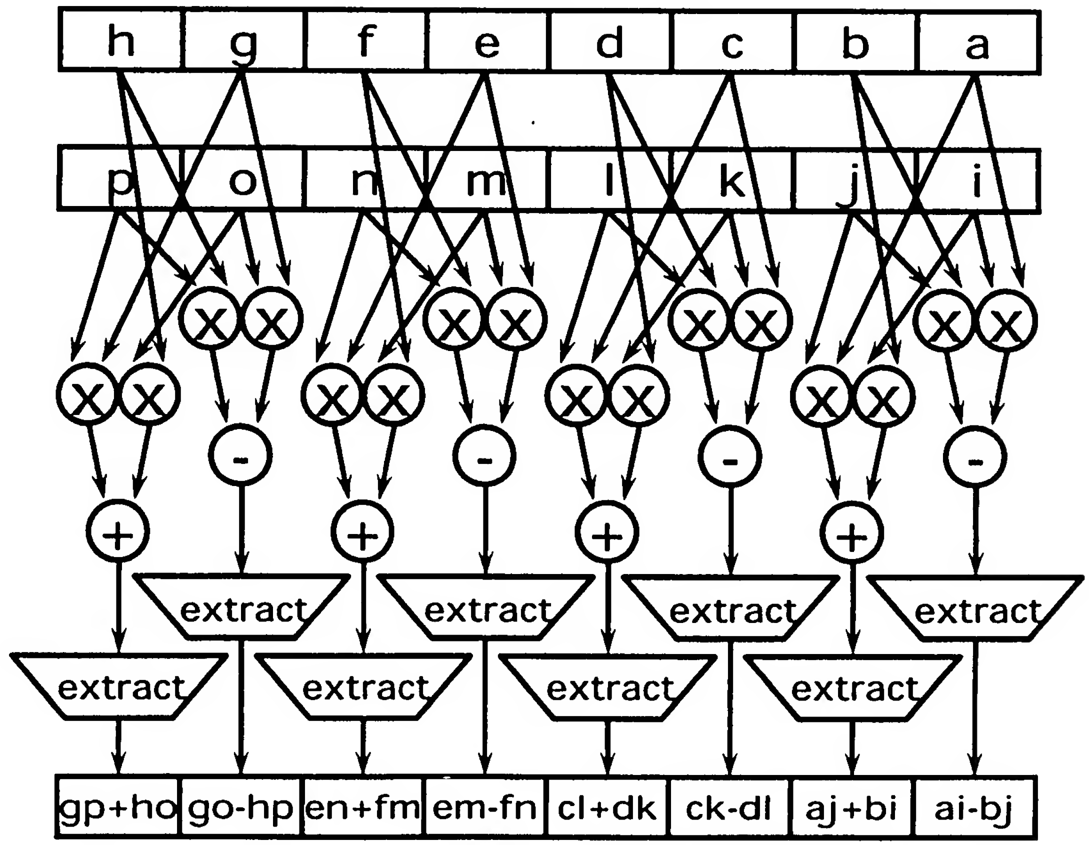
Ensemble multiply add extract

- $rd_{128} = rc_{128} * rb_{128} + rd_{128}$



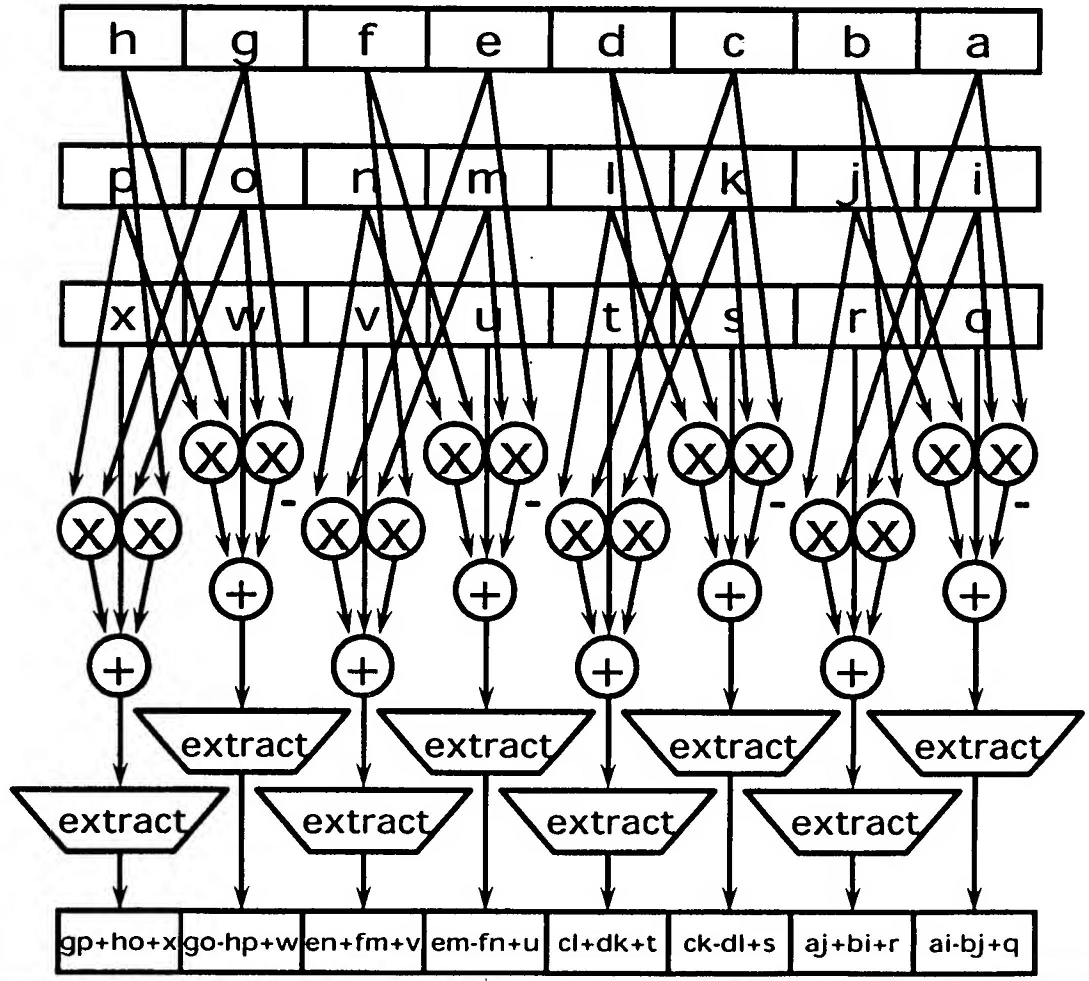
Ensemble multiply extract complex

- $rd_{128} = rc_{128} * rb_{128}$



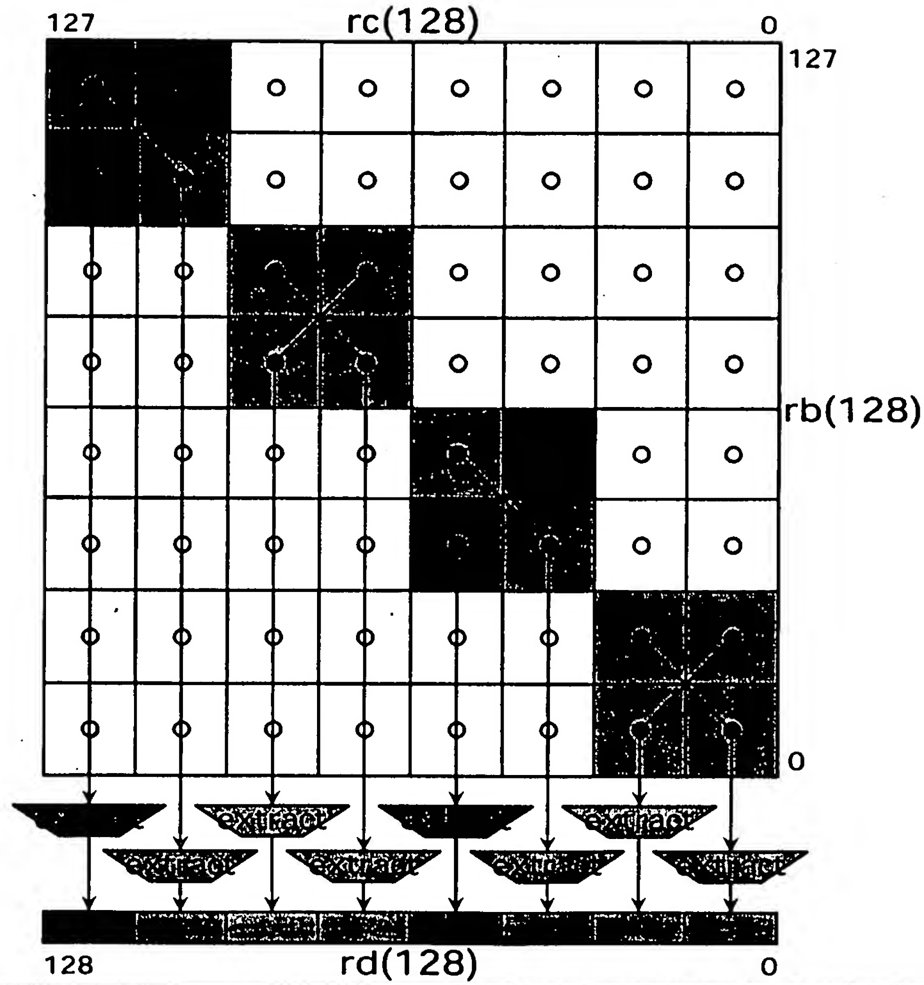
Ensemble multiply add extract complex

- $rd_{128} = rc_{128} * rb_{128} + rd_{128}$



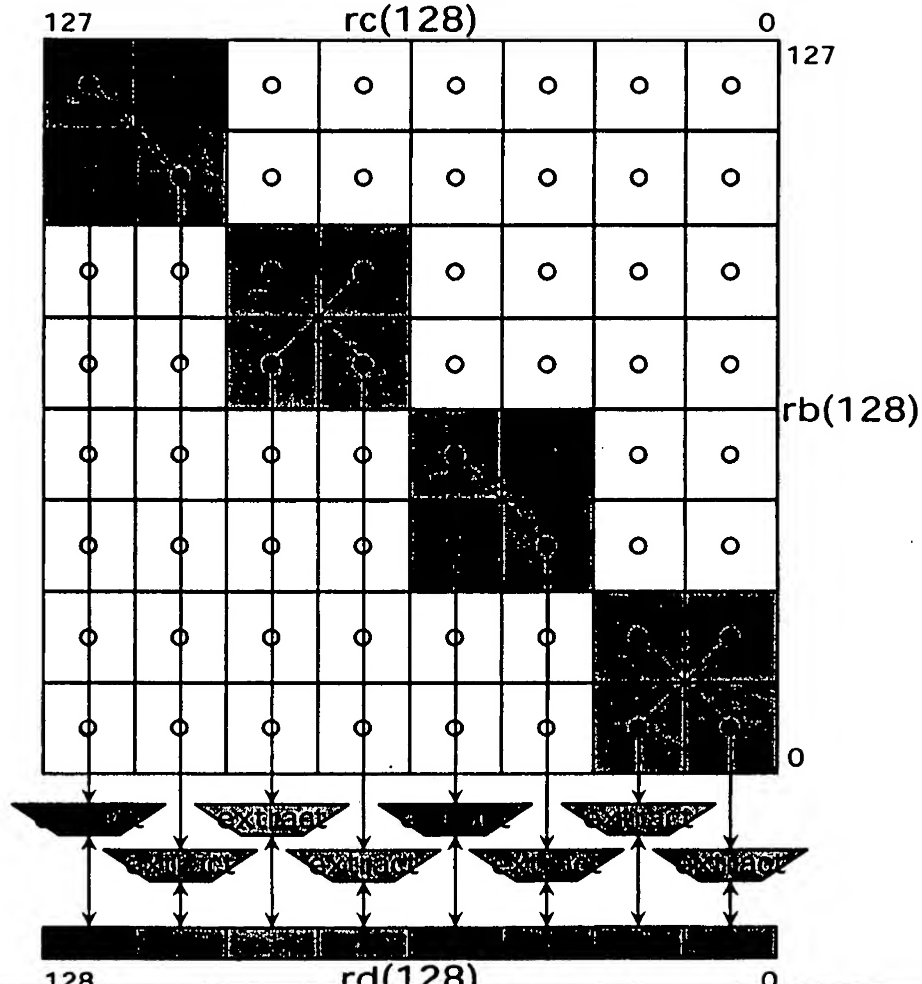
Ensemble multiply extract complex

- $rd_{128} = rc_{128} * rb_{128}$



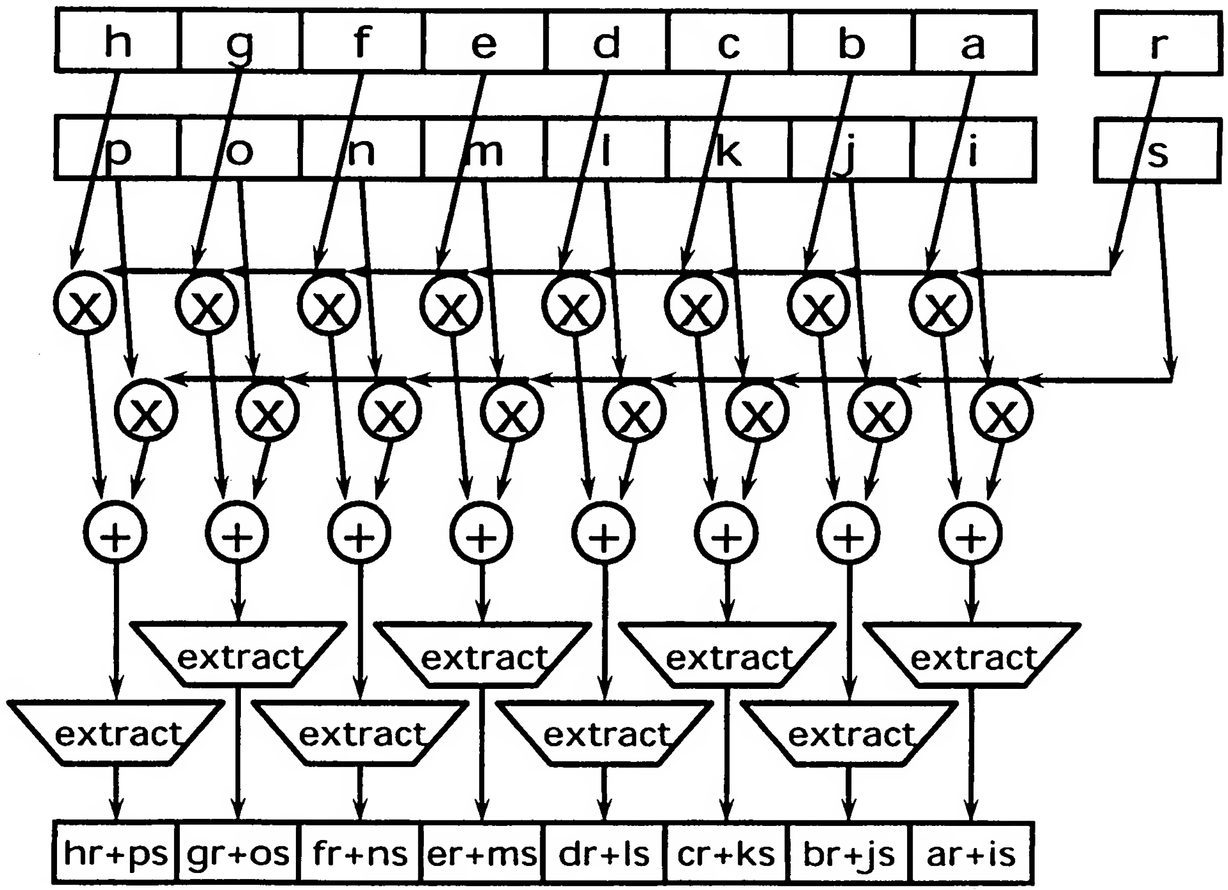
Ensemble multiply add extract complex

- $rd_{128} = rc_{128} * rb_{128} + rd_{128}$



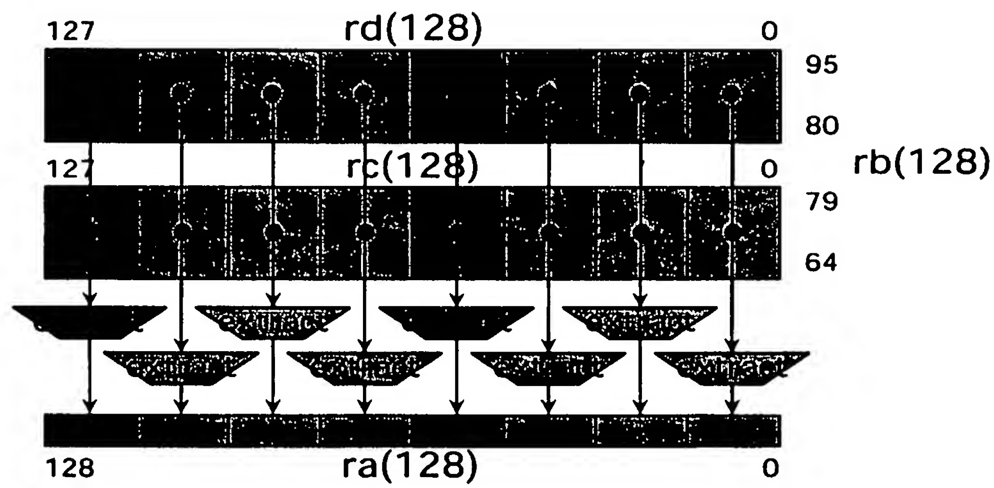
Ensemble scale add extract

- $ra_{128} = rd_{128} * rb_{size} + rc_{128} * rb_{size}$



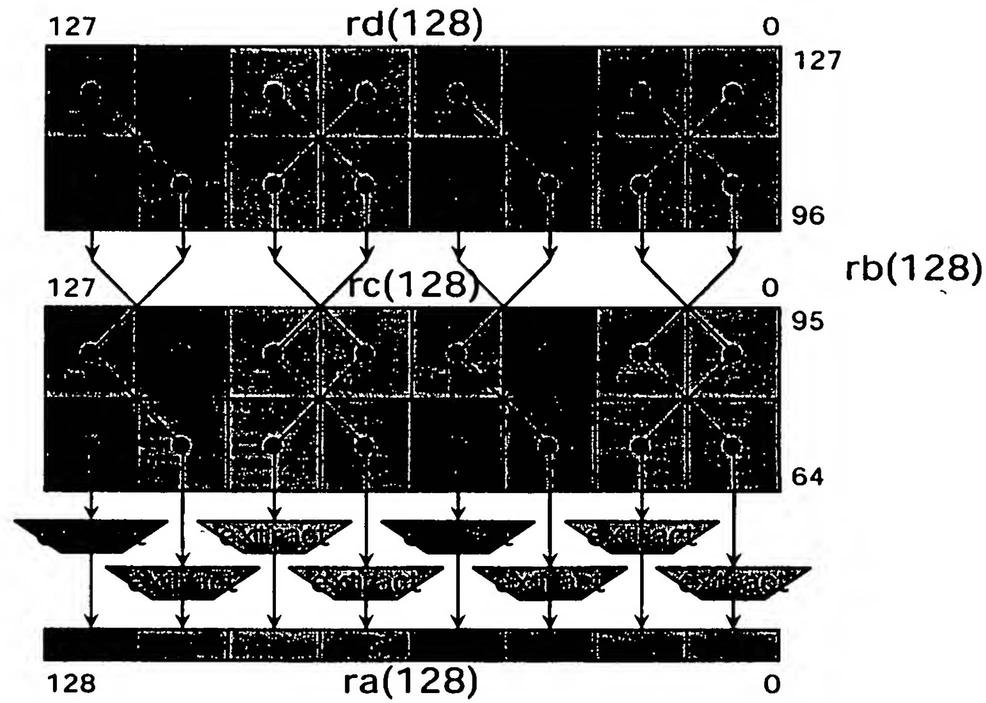
Ensemble scale add extract

- $ra_{128} = rd_{128} * rb_{size} + rc_{128} * rb_{size}$



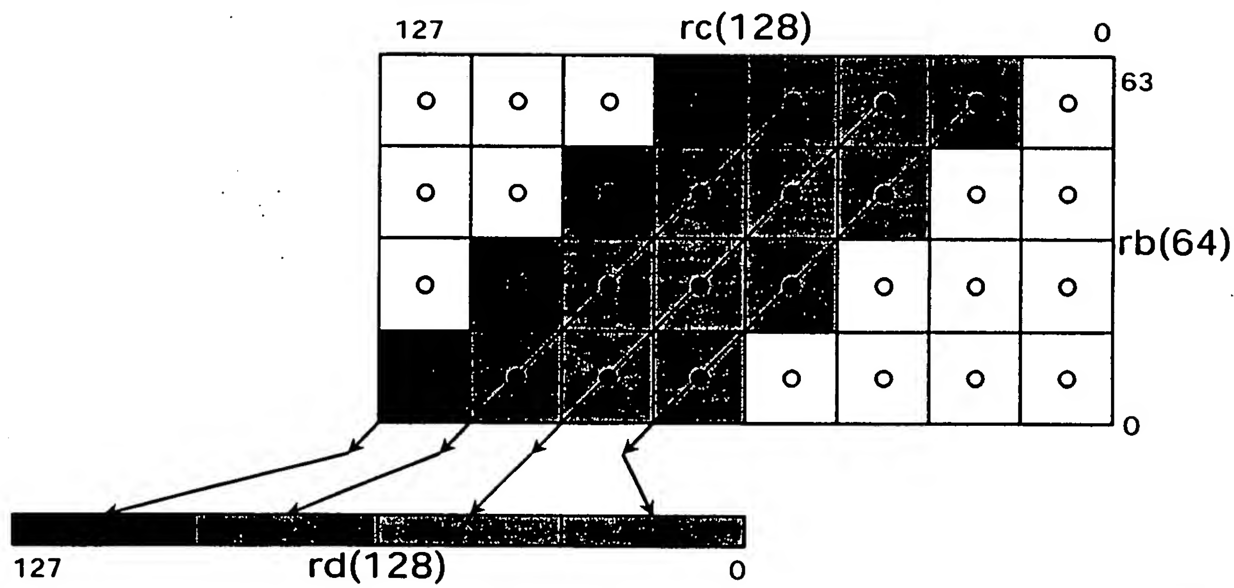
Ensemble scale add extract complex

- $ra_{128} = rd_{128} {}^{*} rb_{size*2} + rc_{128} {}^{*} rb_{size*2}$



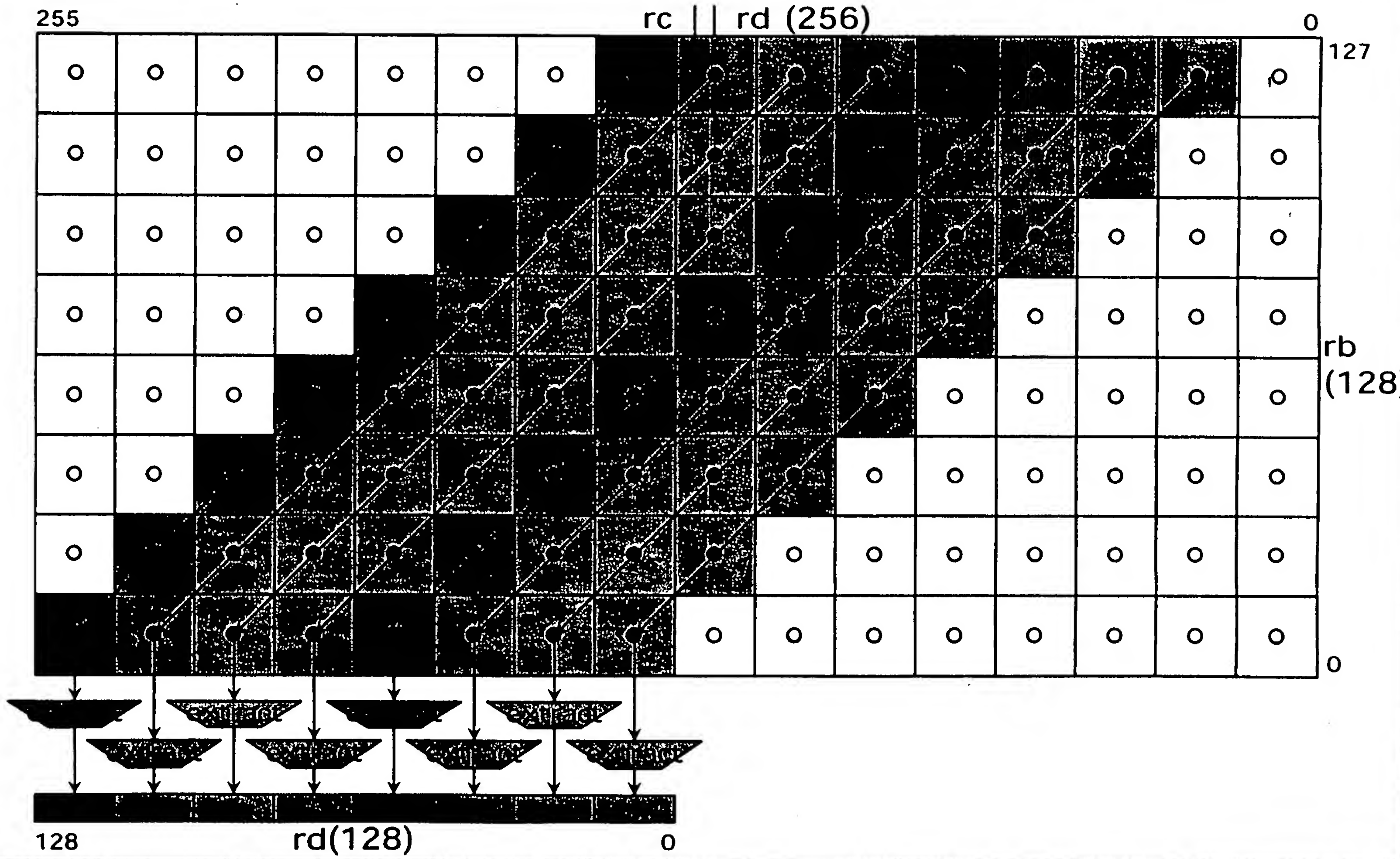
Ensemble convolve

- $rd_{128} = rc_{128} * rb_{64}$



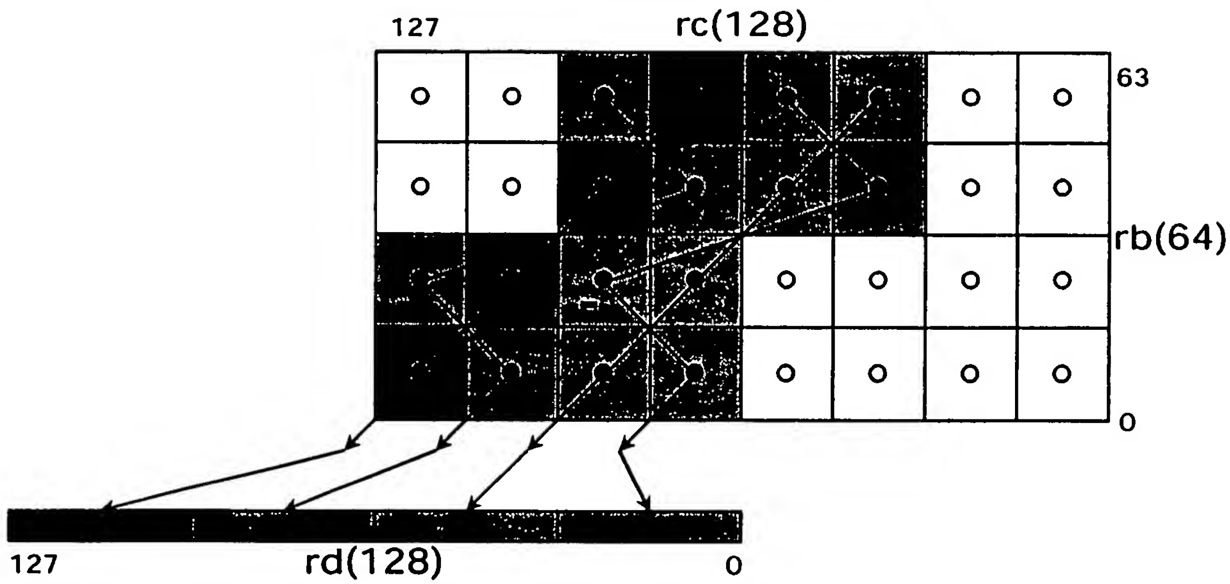
Ensemble convolve extract

- $rd_{128} = (rd||rc)_{256} * rb_{128}$



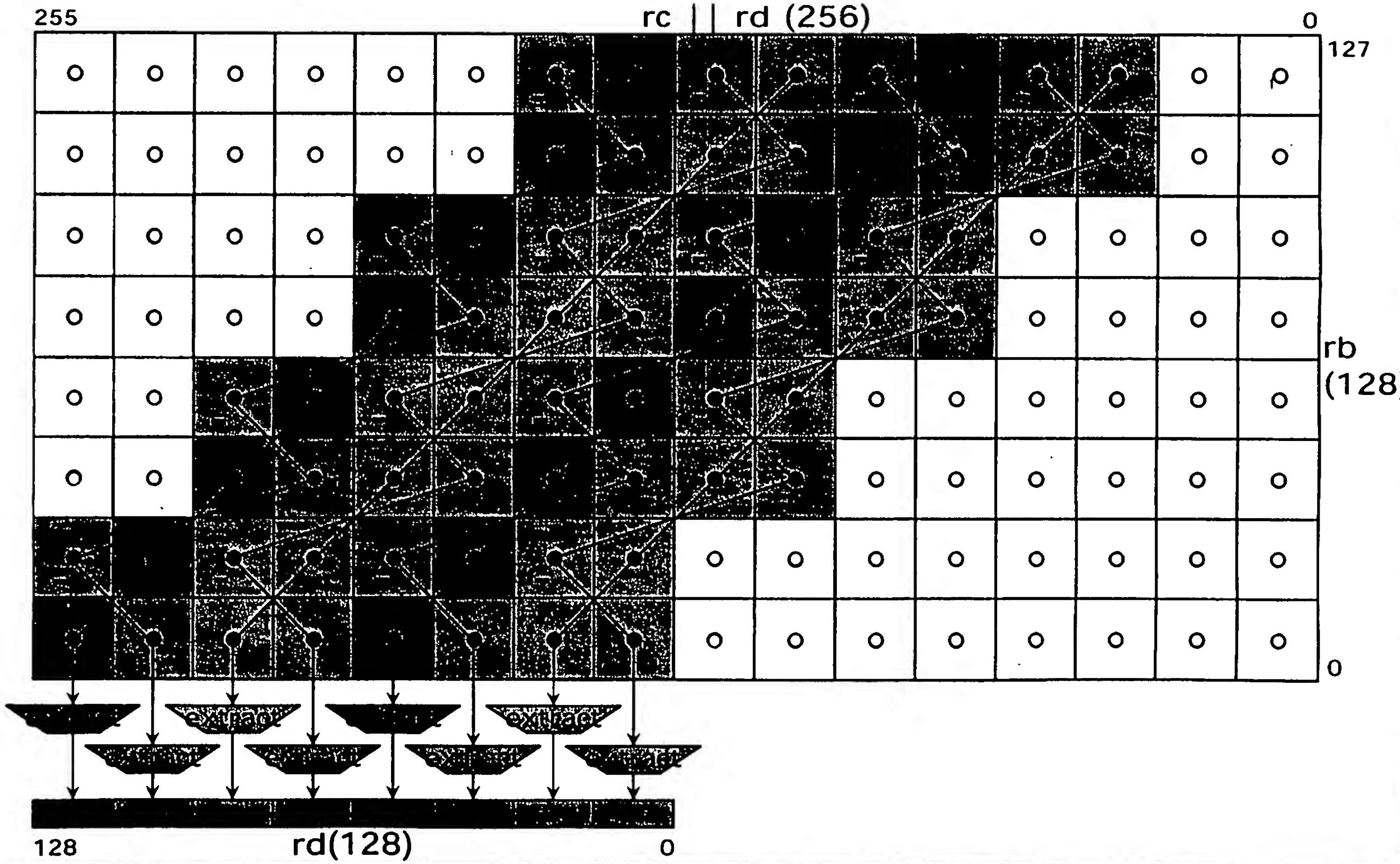
Ensemble convolve complex

- $rd_{128} = rc_{128} * rb_{64}$



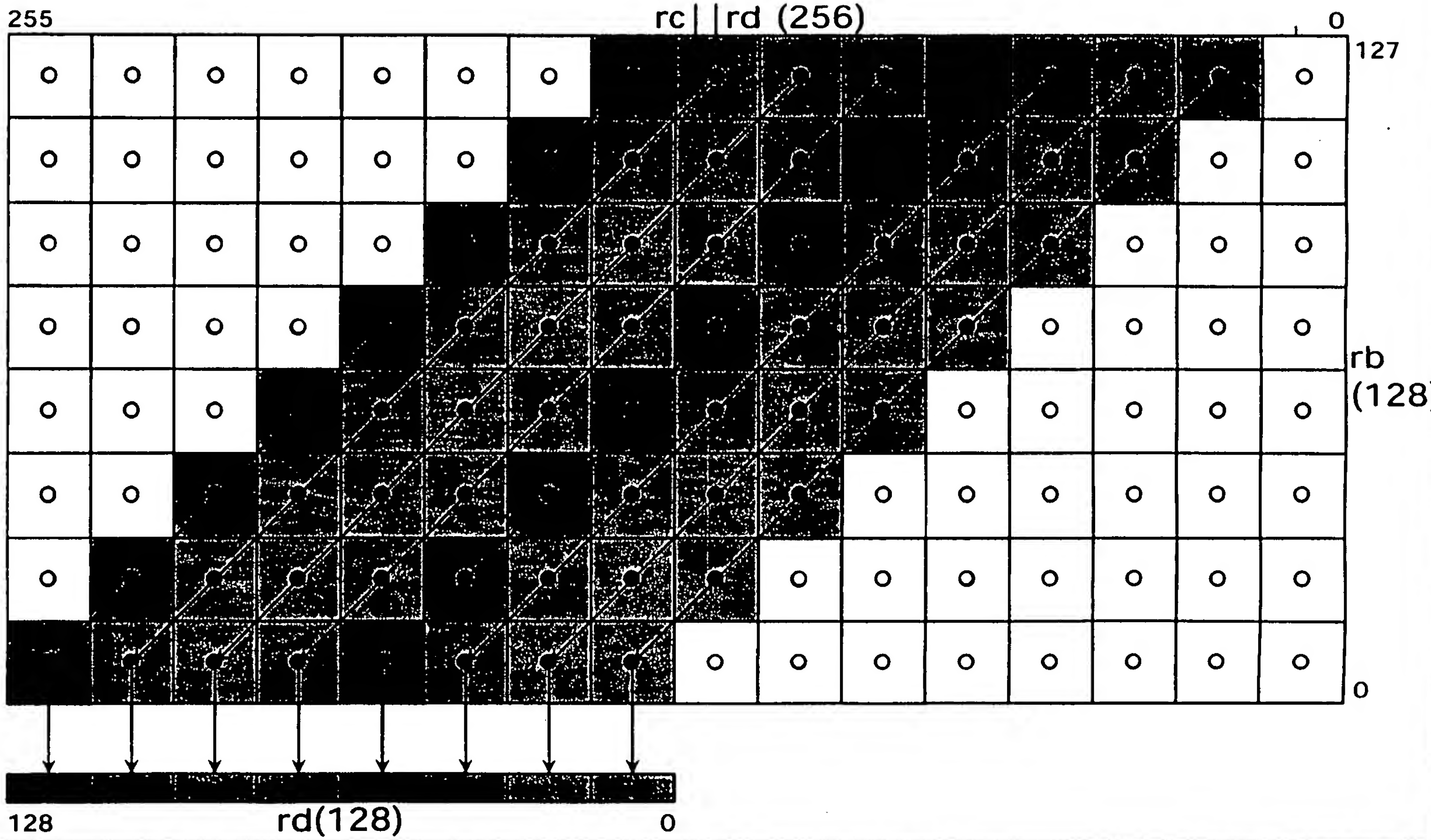
Ensemble convolve extract complex

- $rd_{128} = (rc||rd)_{256} * rb_{128}$



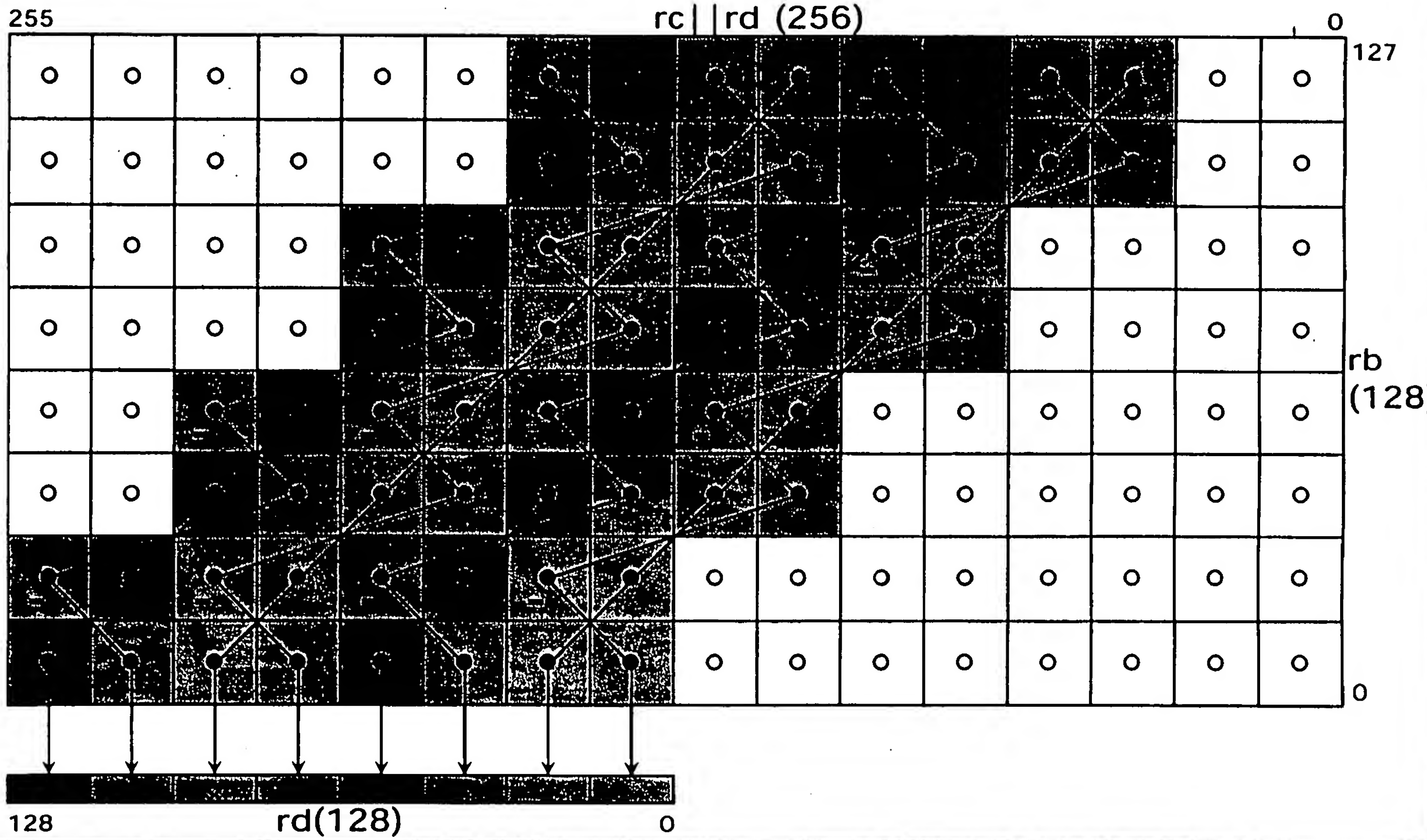
Ensemble convolve floating-point

- $rd_{128} = (rc||rd)_{256} * rb_{128}$



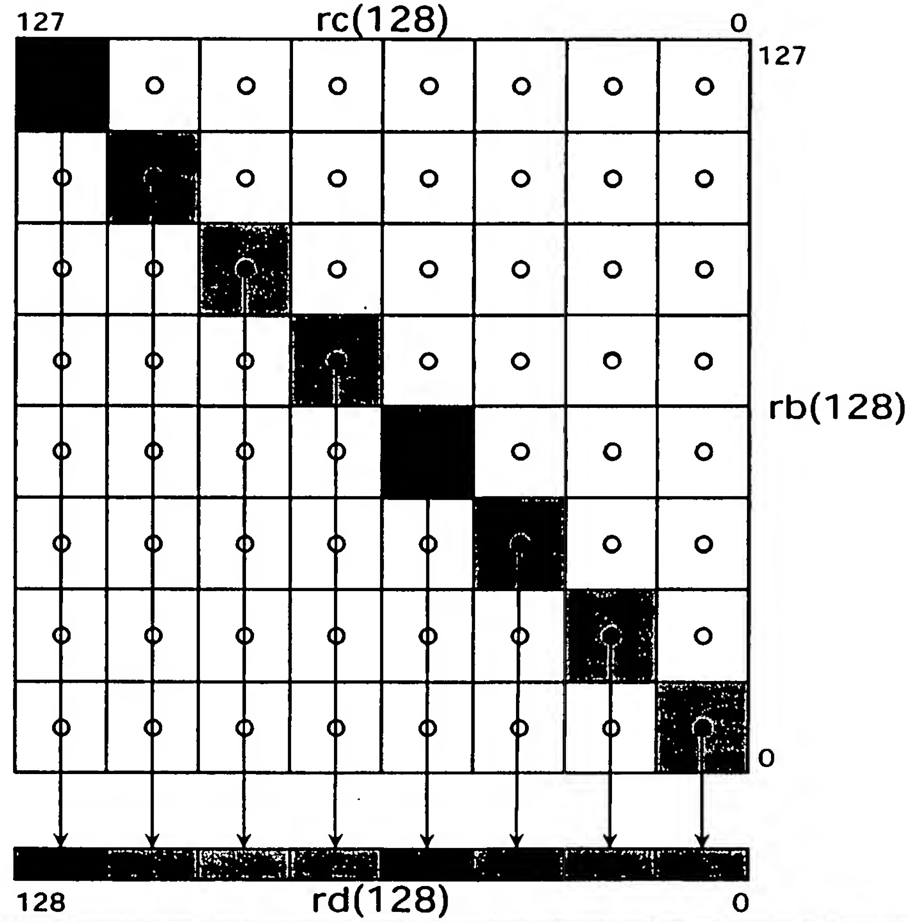
Ensemble convolve complex floating-point

- $rd_{128} = (rc||rd)_{256} * rb_{128}$



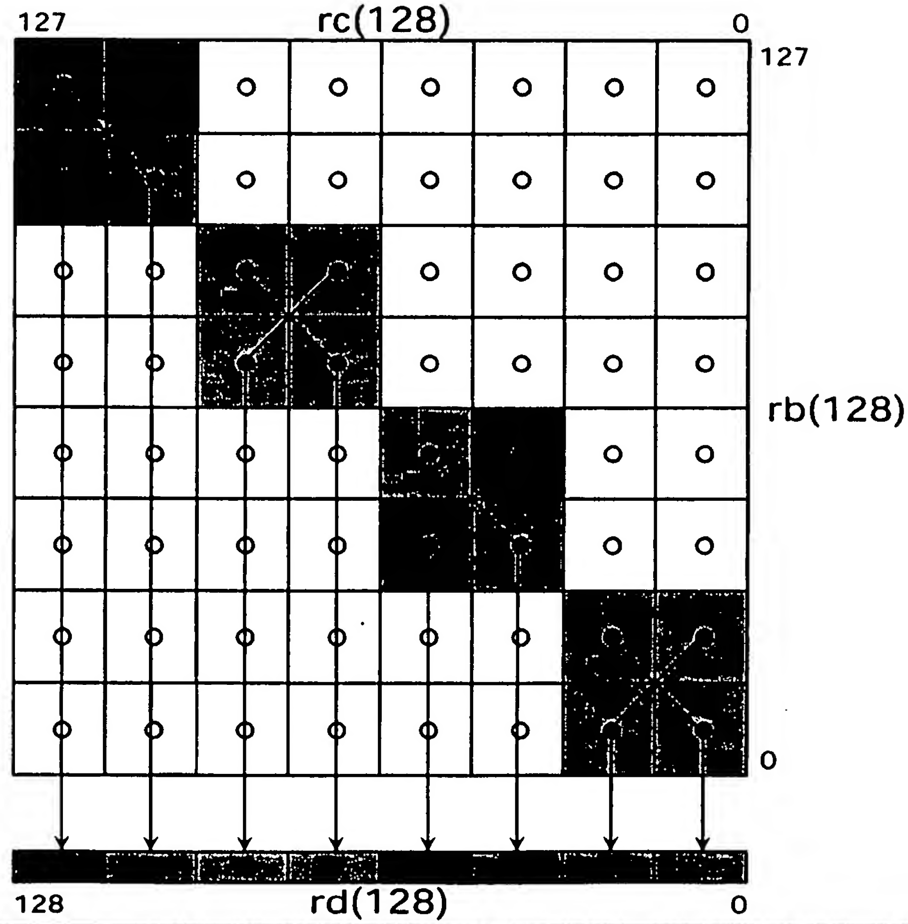
Ensemble multiply floating-point

- $rd_{128} = rc_{128} * rb_{128}$



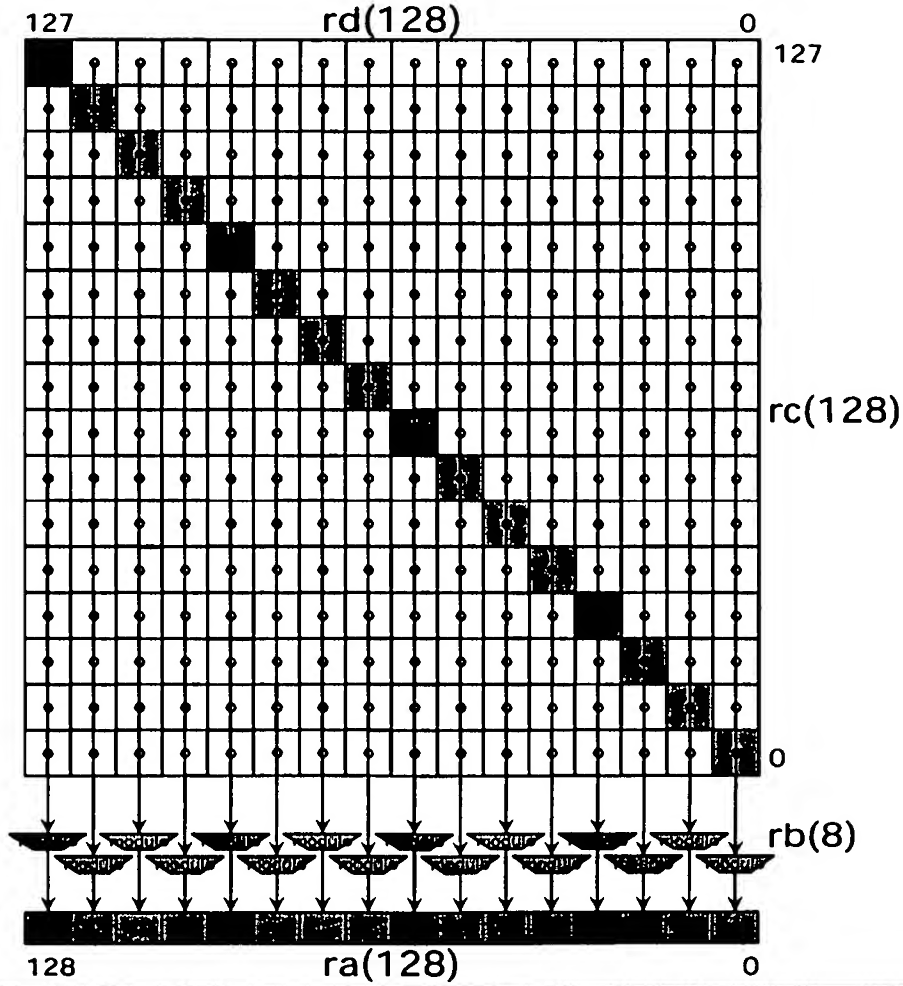
Ensemble multiply floating-point complex

- $rd_{128} = rc_{128} * rb_{128}$



Ensemble multiply Galois

- $ra_{128} = rd_{128} * rc_{128} \bmod rb_8$



Wide Instructions

- Wide Multiply Matrix — E
- Wide Switch — X
- Wide Table — L

MicroUnity

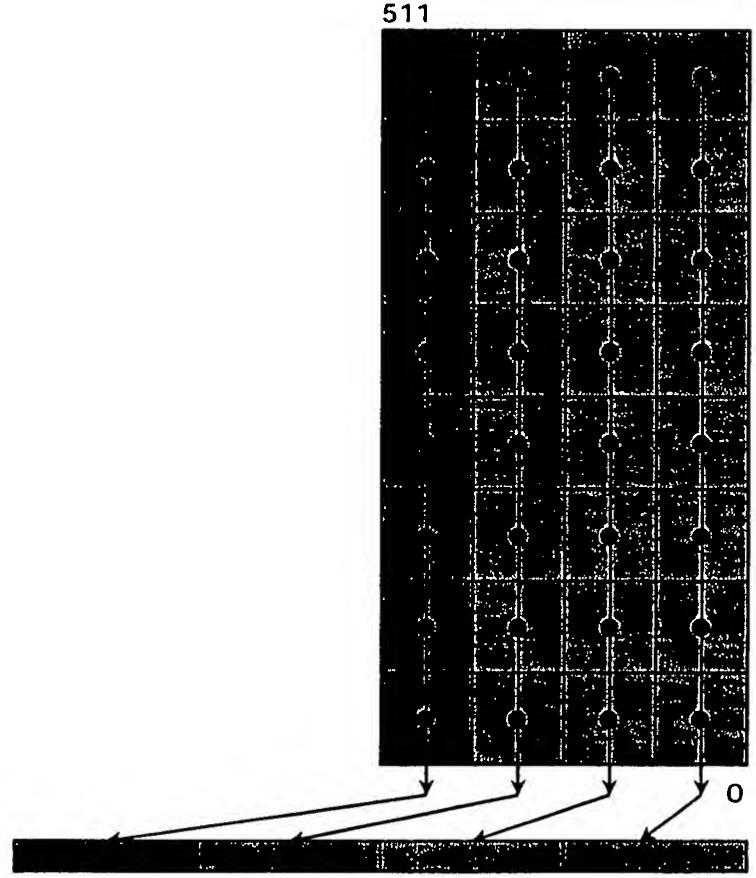
Wide size and shape

- operations up to 128x128
- full size not always required
- optional bits set in address
  - sets operand size
  - sets operand width
- operand aligned to specified size

- smaller size *may* use fewer cycles
  - to load operand cache
  - to perform operation

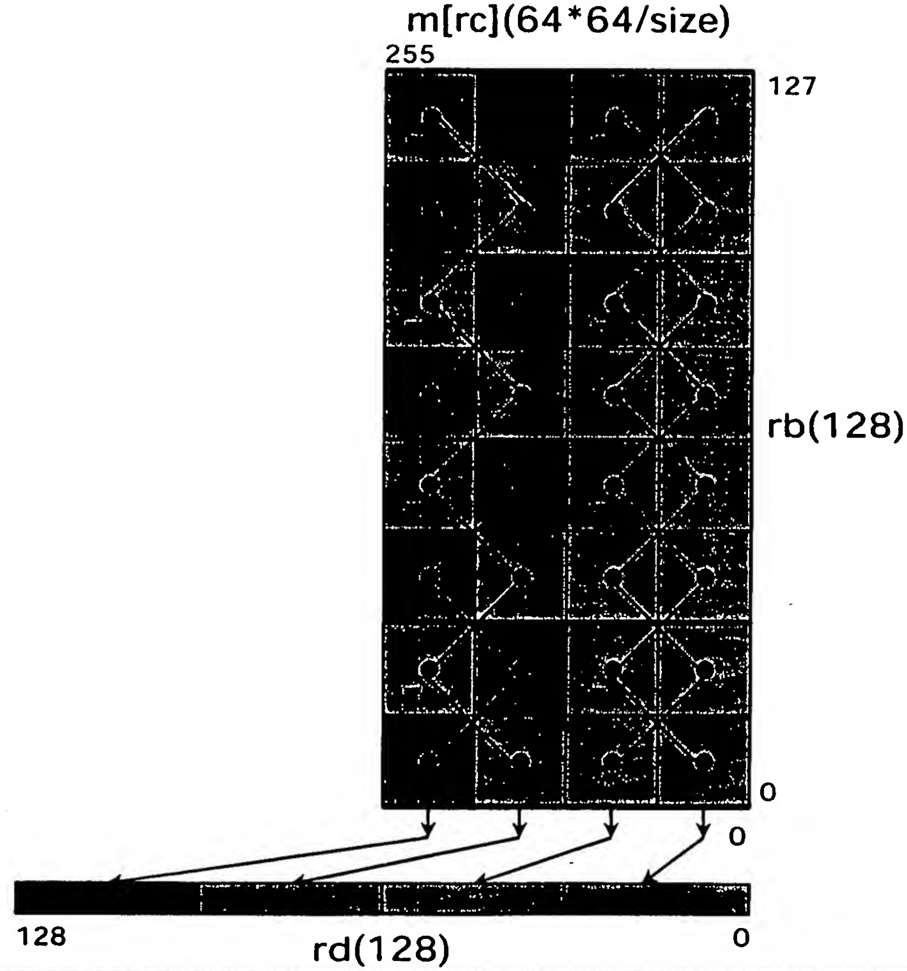
Wide multiply matrix

- $rd_{128} = m[rc]_{(128*64/size)} * rb_{128}$



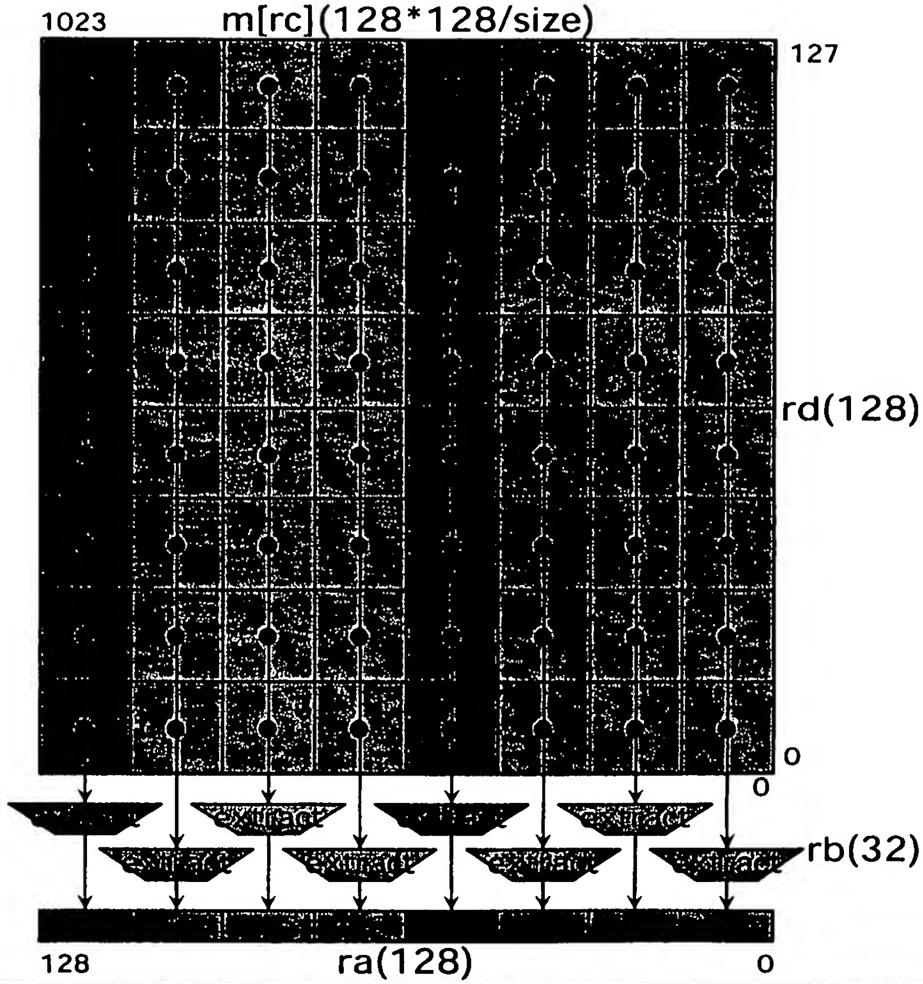
Wide multiply matrix complex

- $rd_{128} = m[rc]_{(64*64/size)} * rb_{128}$



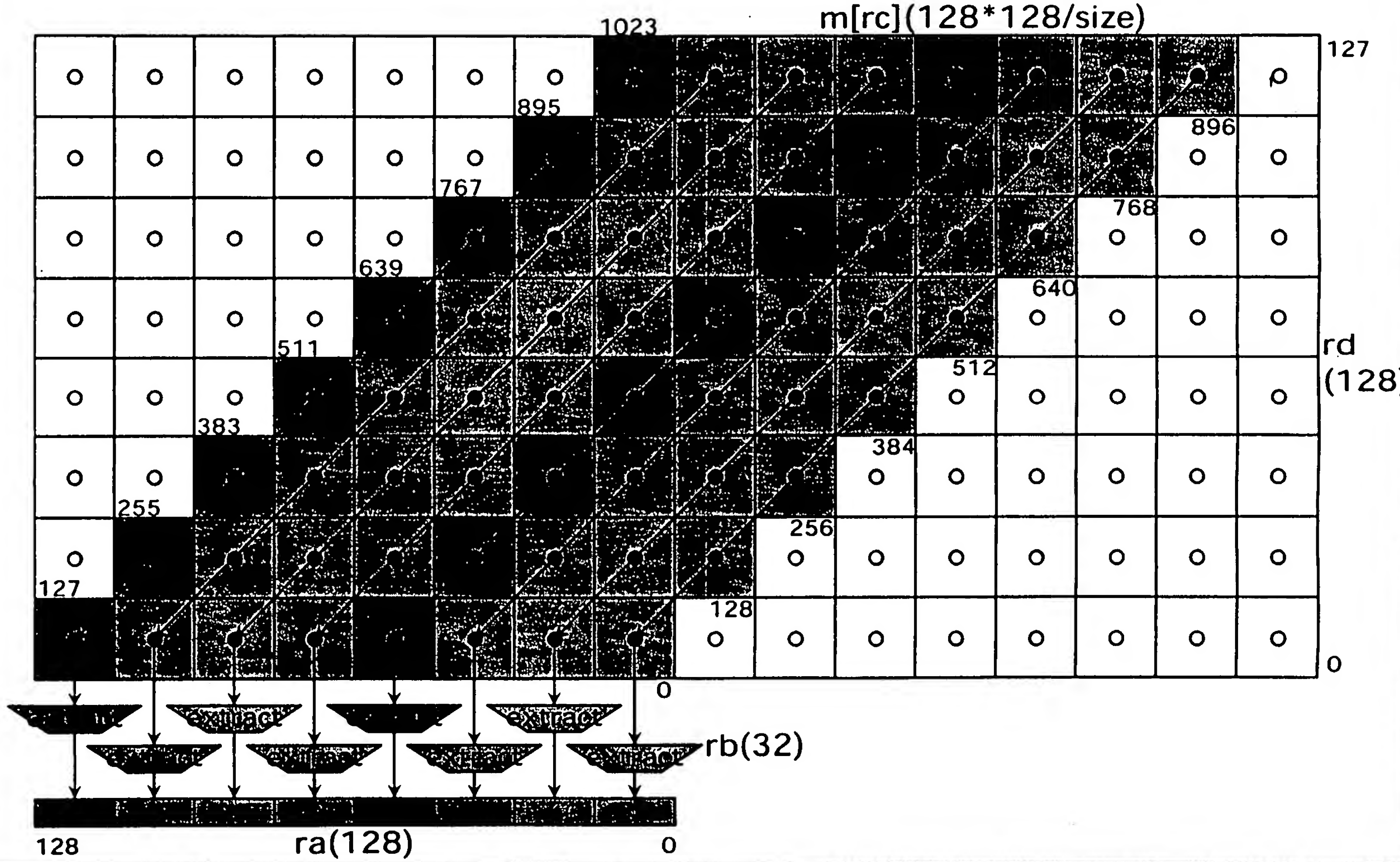
Wide multiply matrix extract

- $ra_{128} = m[rc]_{128*128/size} * rd_{128}$



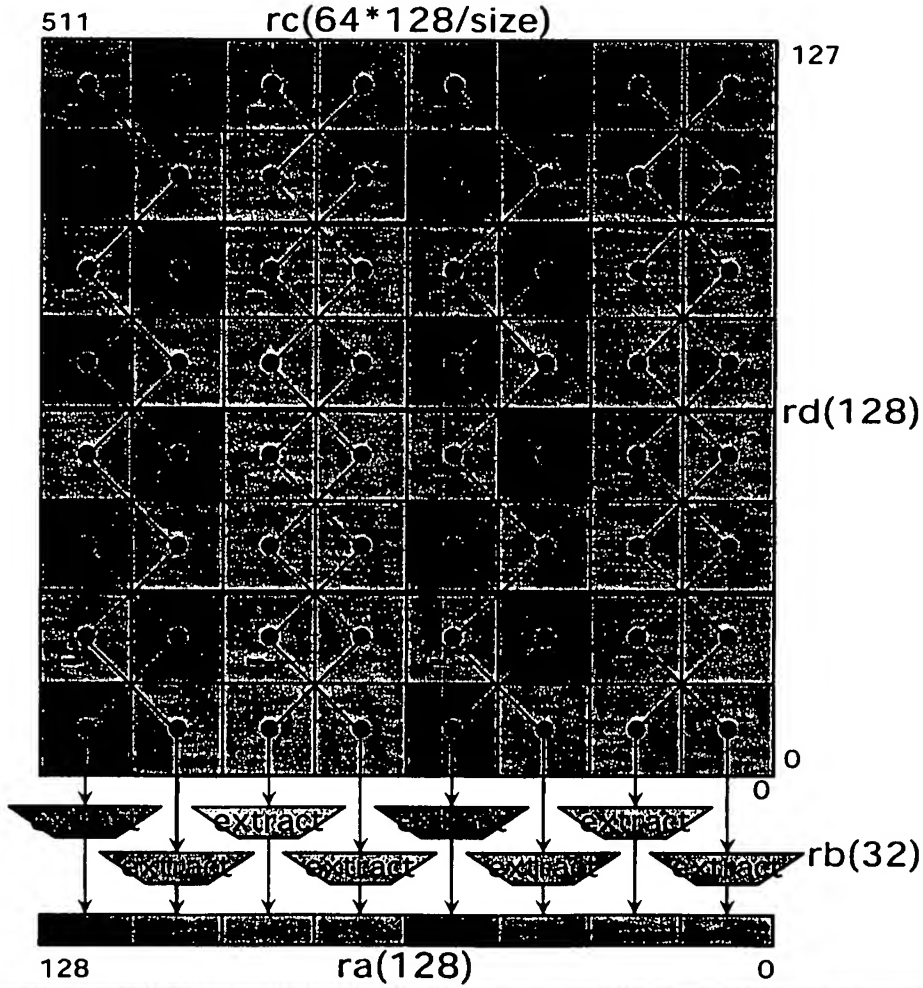
Wide multiply matrix extract

- $ra_{128} = m[rc]_{128*128/size} * rd_{128}$



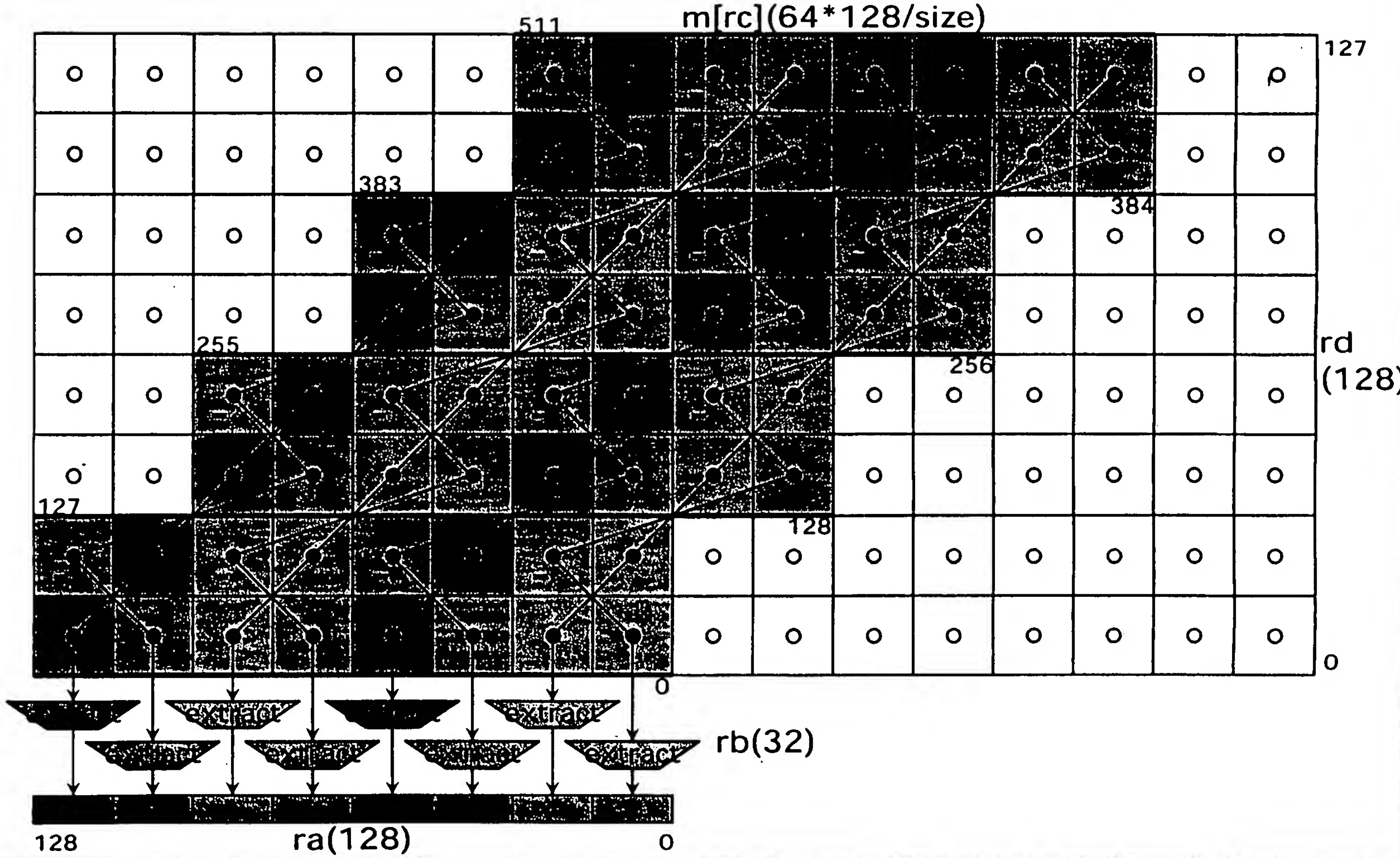
Wide multiply matrix extract complex

- $ra_{128} = m[rc]_{64*128/size} * rd_{128}$



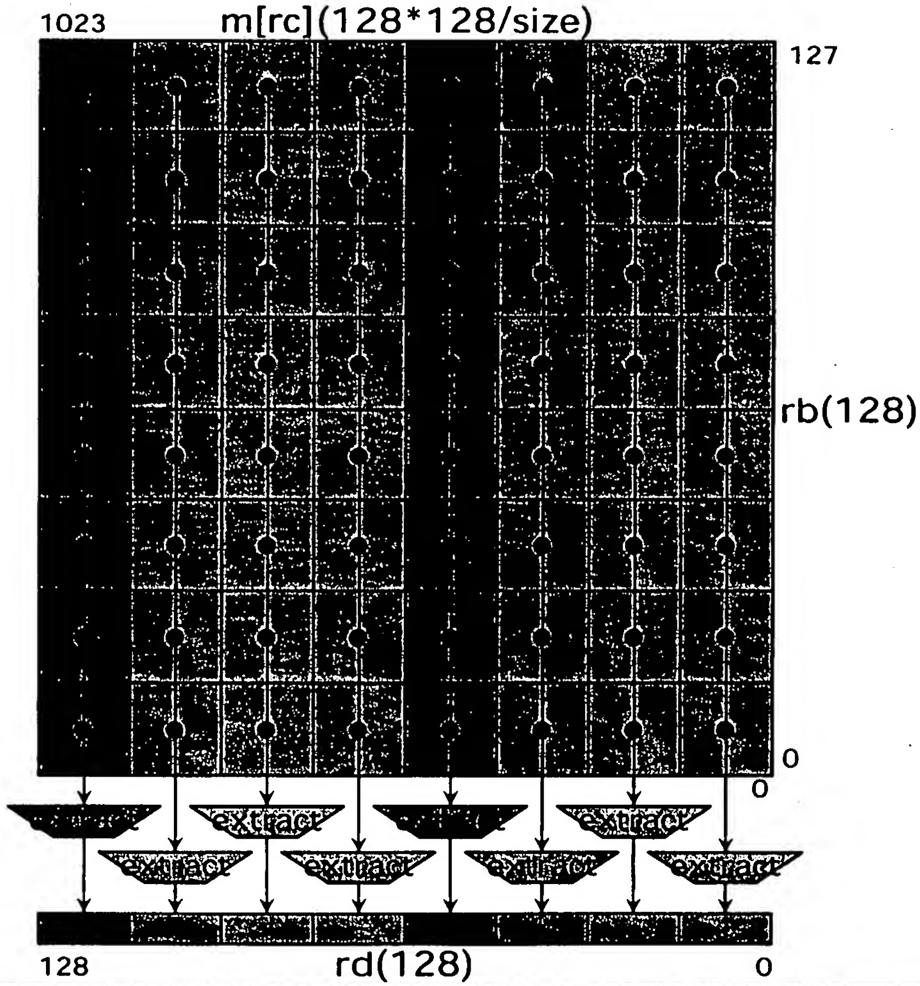
Wide multiply extract complex

- $ra_{128} = m[rc]_{64*128/size} * rd_{128}$



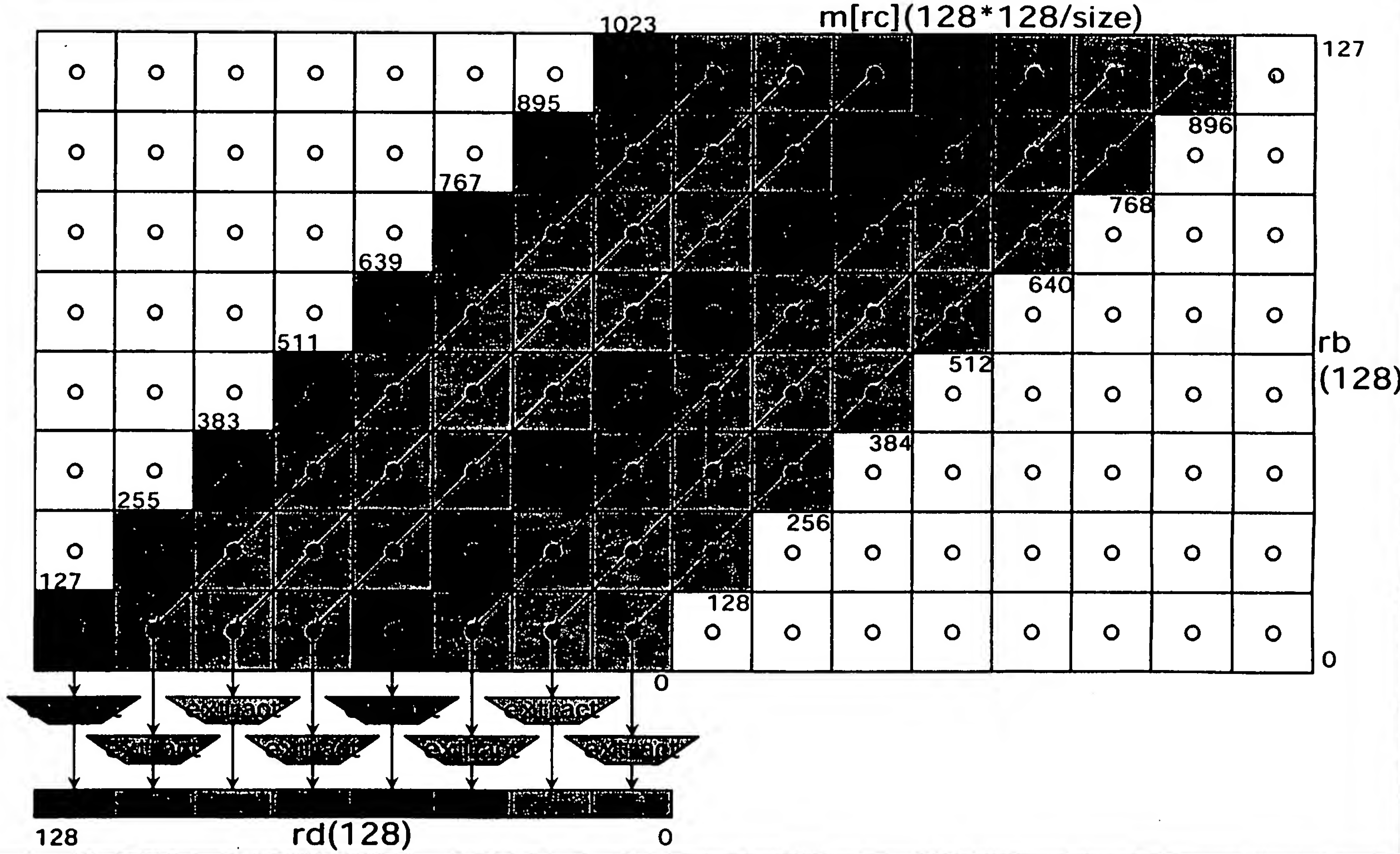
Wide multiply matrix extract immediate

- $rd_{128} = m[rc]_{128*128/size} * rb_{128}$



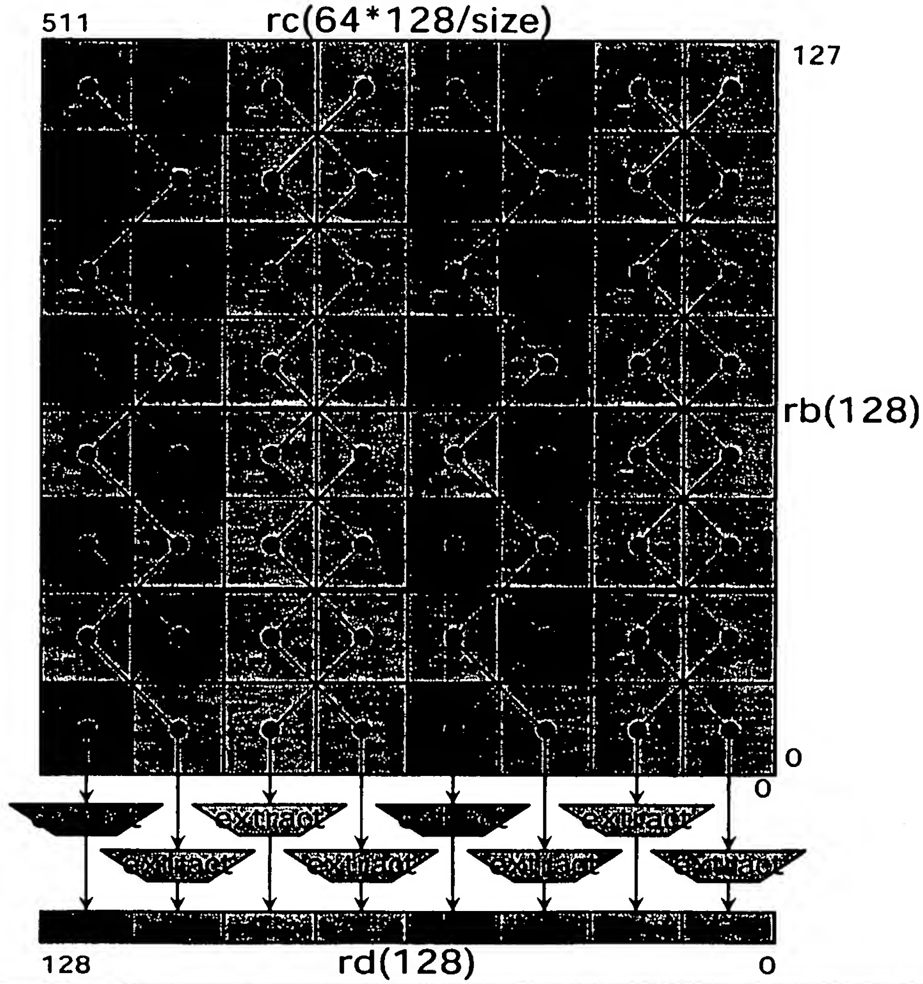
Wide multiply matrix extract immediate

- $rd_{128} = m[rc]_{128*128/size} * rb_{128}$



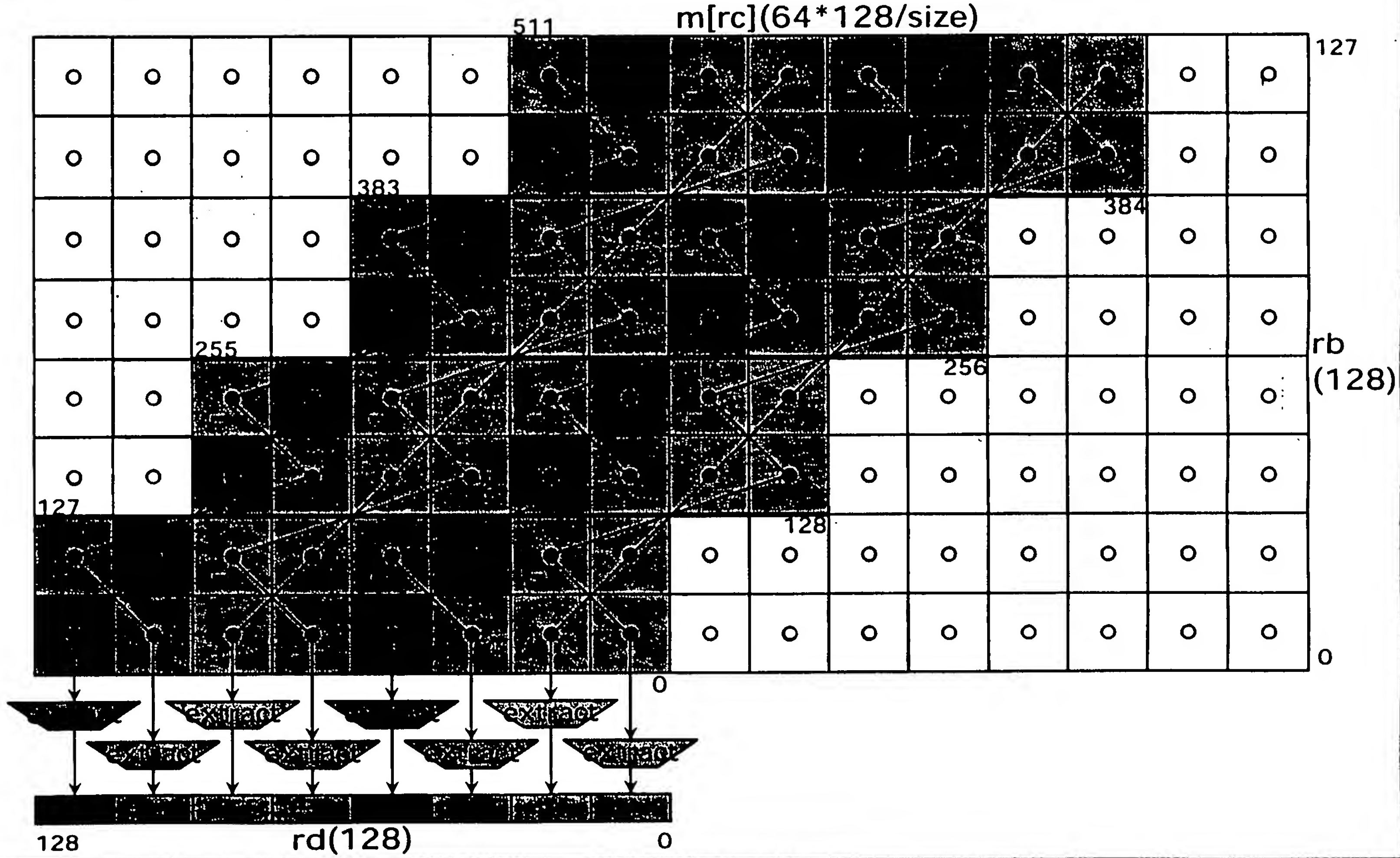
Wide multiply matrix extract immediate complex

- $rc_{128} = m[rc]_{64*128/size} * rb_{128}$



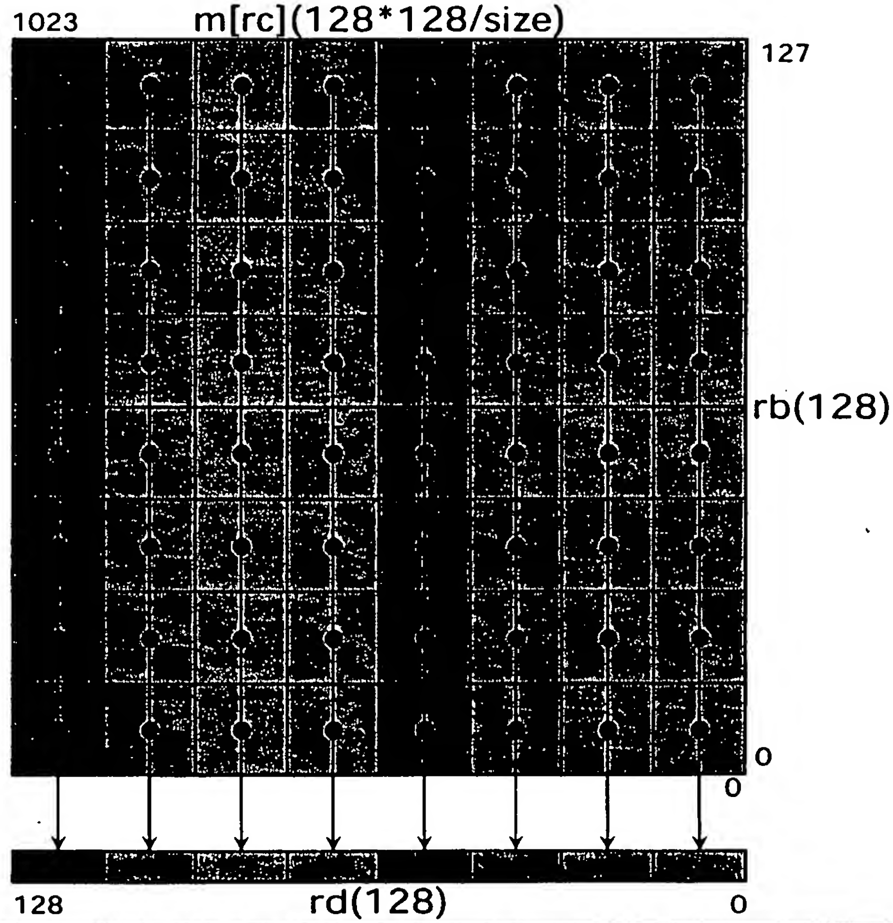
Wide multiply extract immediate complex

- $rd_{128} = m[rc]_{64*128/size} * rb_{128}$



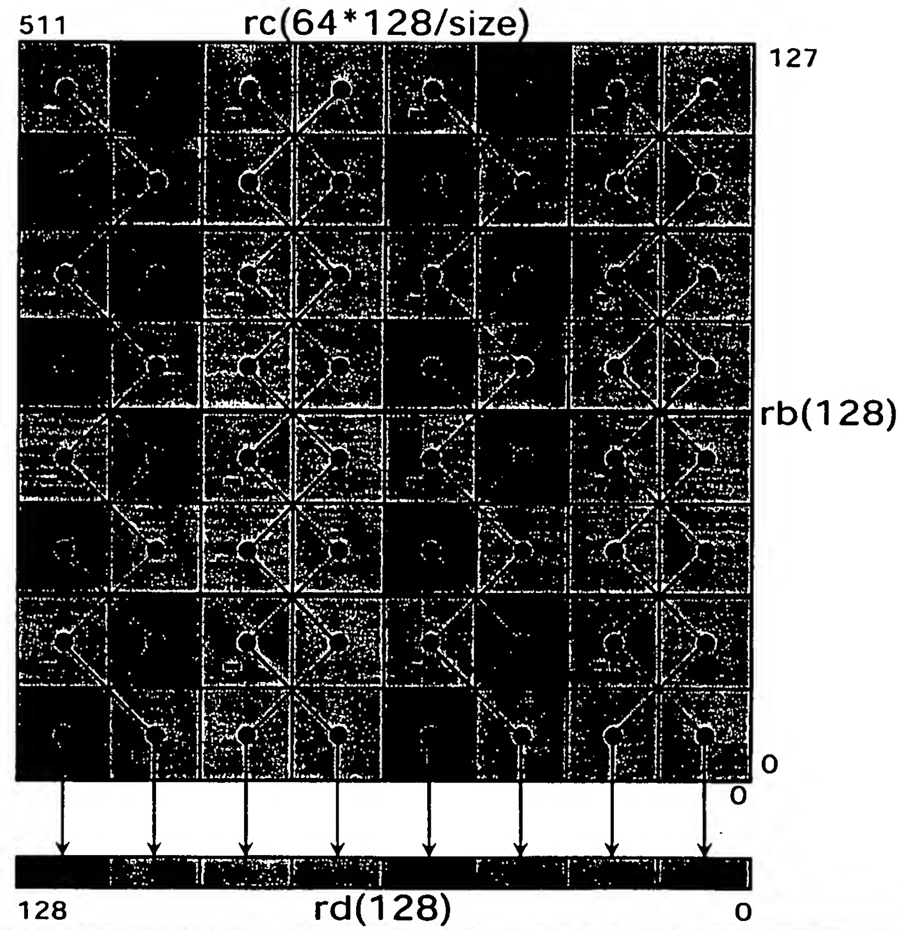
Wide multiply matrix floating-point

- $rd_{128} = m[rc]_{128*128/size} * rb_{128}$



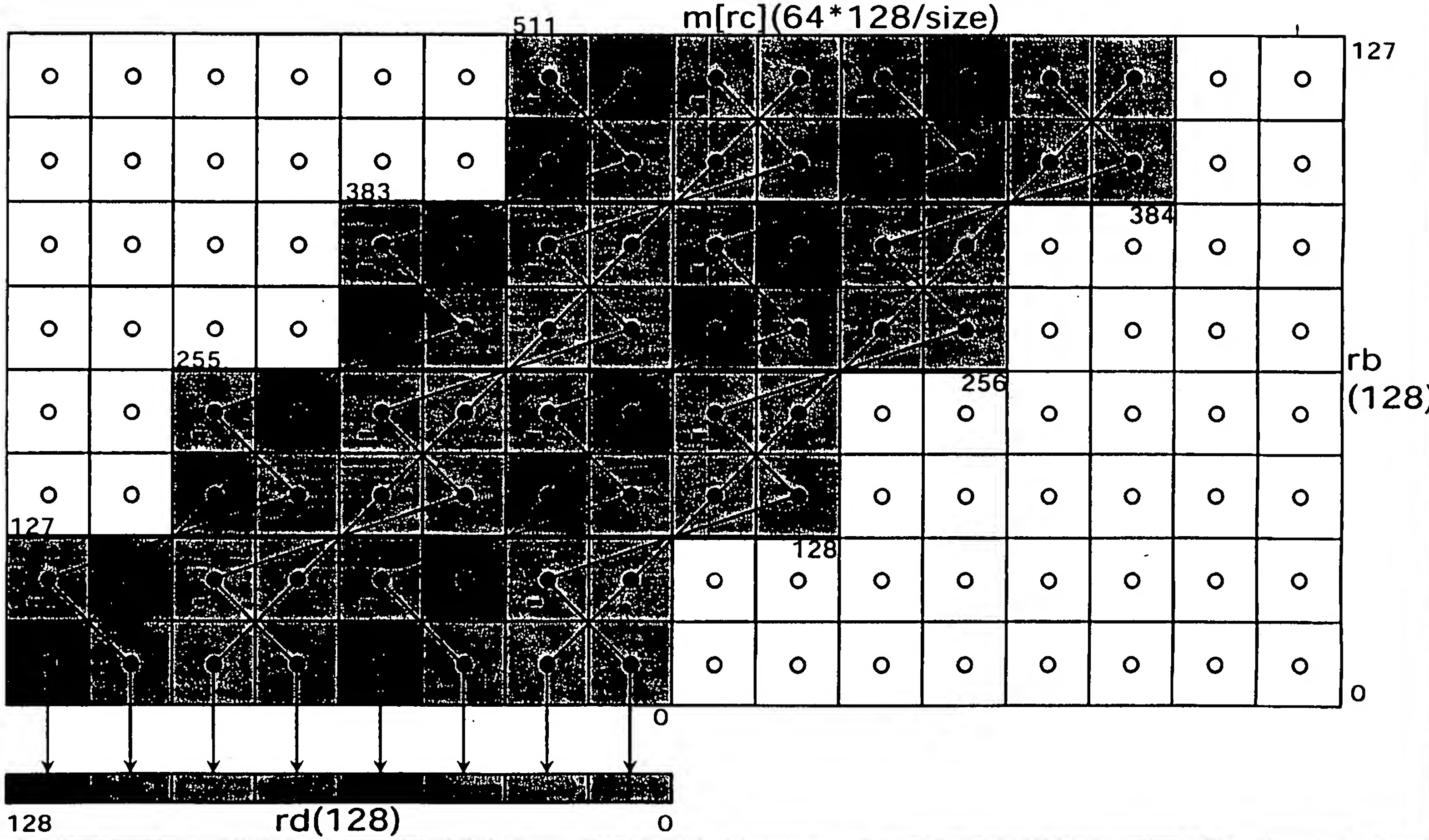
Wide multiply matrix complex floating-point

- $rd_{128} = m[rc]_{64*128/size} * rb_{128}$



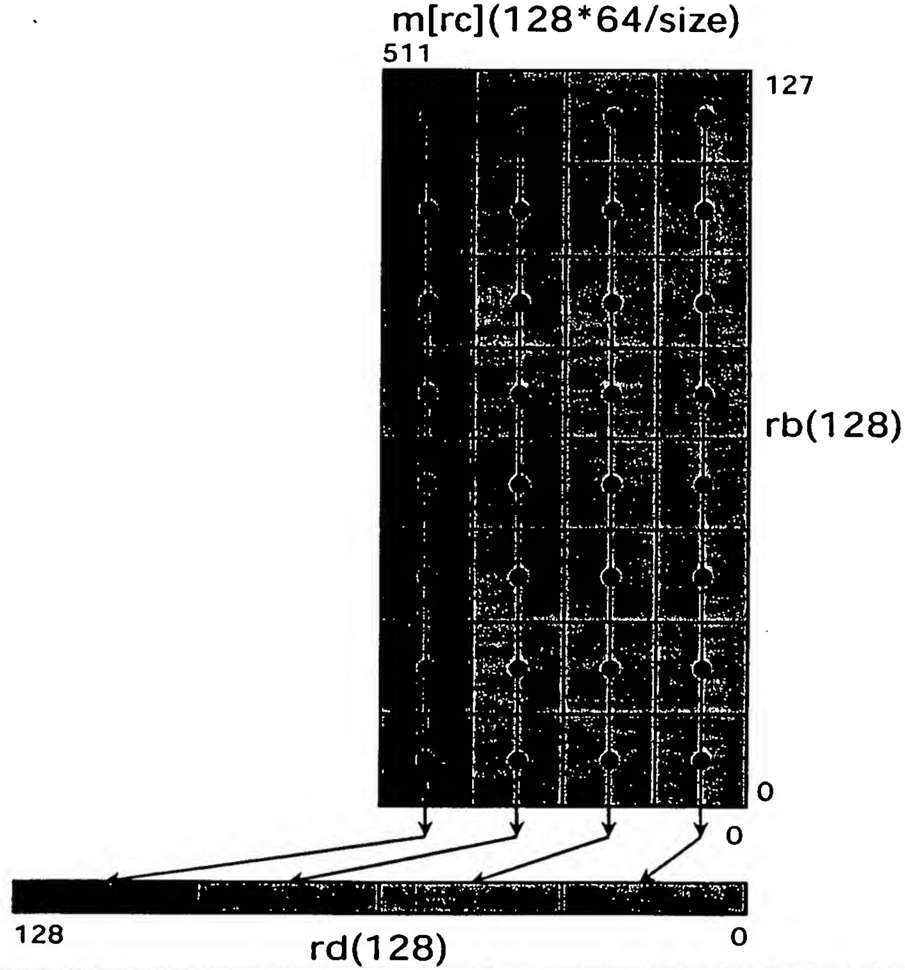
Wide multiply matrix complex floating-point

- $rd_{128} = m[rc]_{64*128/size} * rb_{128}$



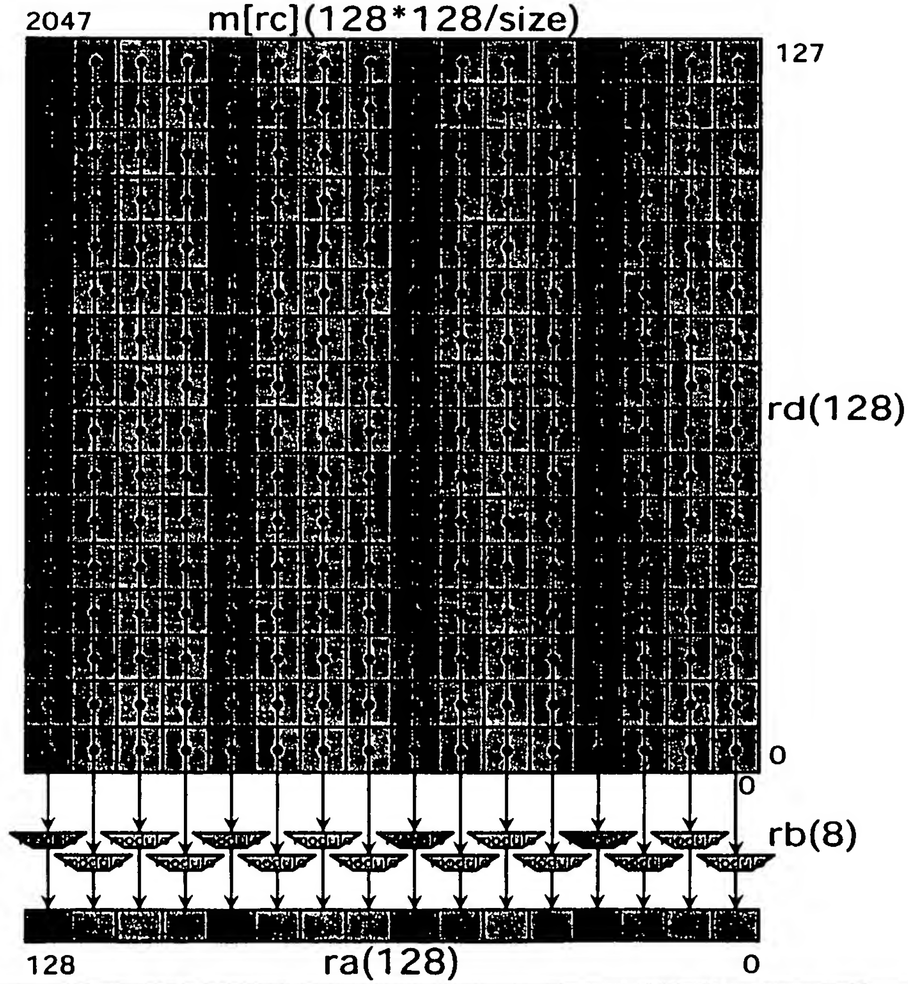
Wide multiply matrix polynomial

- $rd_{128} = m[rc]_{(128*64/size)} * rb_{128}$



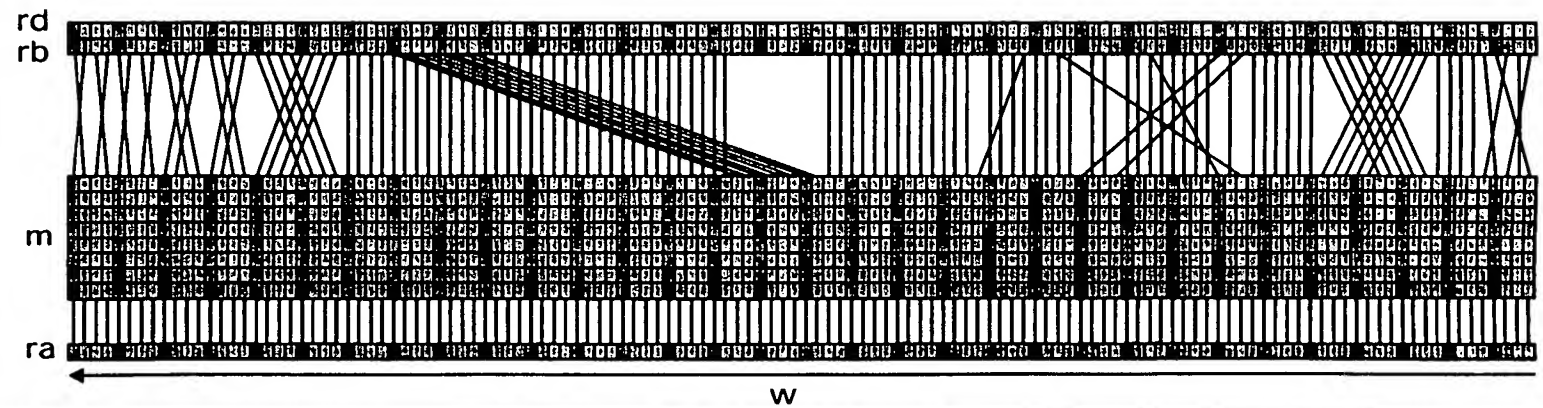
Wide multiply matrix Galois

- $ra_{128} = m[rc]_{128*128/size} * rd_{128} \bmod rb_8$



Wide switch

- $j(i) = m[rc]_{7w+i,6w+i,5w+i,4w+i,3w+i,2w+i,w+i,i}$
- $ra_i = (rd||rb)_j$, $i=0..127$
- rc specifies address and w
  - rc = base + w/2



Wide Table

- Table lookup
  - msize: total table size
  - wsize: table width
  - vsize: table depth
  - gsize: Group size (table granularity)

- $j(i) = b_{lvsize-1+i..i*wsize+i|wsize-1..0}$
- $rd_{i+gsize-1..i} = m[rc]_{j+gsize-1..j}$, $i=0..128\text{-}gsize$ by gsize
- rc specifies address, msize, wsize
  - rc = base + msize/16 + wsize/16
  - vsize = msize/wsize

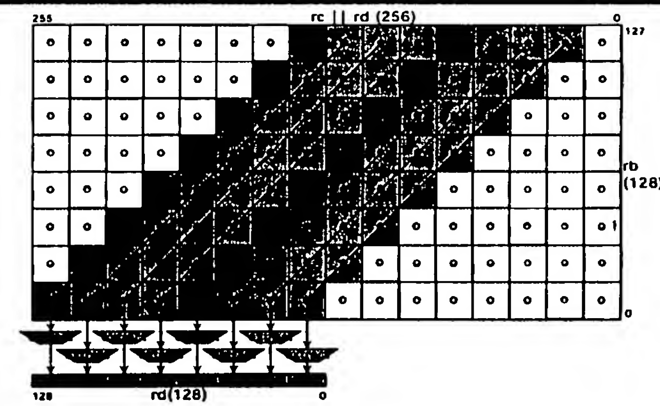
MicroUnity

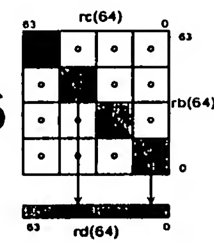
Summary

- Order-of-magnitude multiply performance increase
  - matrix multiply
  - convolve
- Wide switch: bit permutation
- Wide select: table lookup

BroadMX™ vs. MMX™

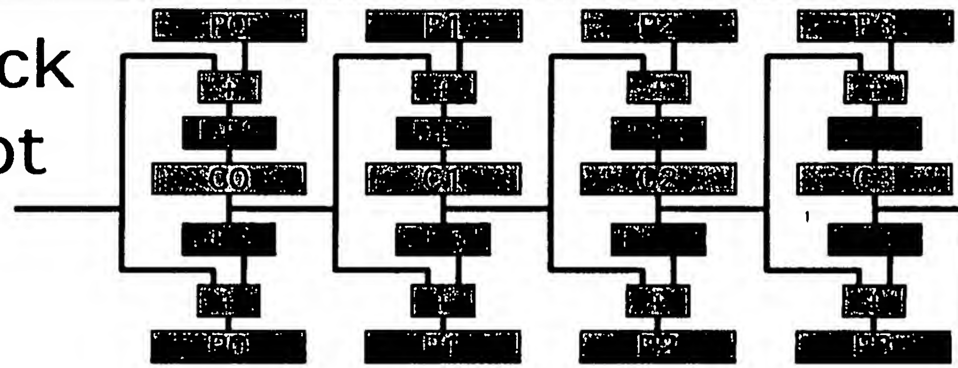
- Convolve Extract
  - 64 Multiplies
  - 56 Adds
  - 8 Extract w/round
- MMX Instructions
  - 16 MOV
  - 16 PMADDWD
  - 12 PADDD
  - 8 PSHW
  - 4 PSHR
  - 2 PACK
  - 58 total



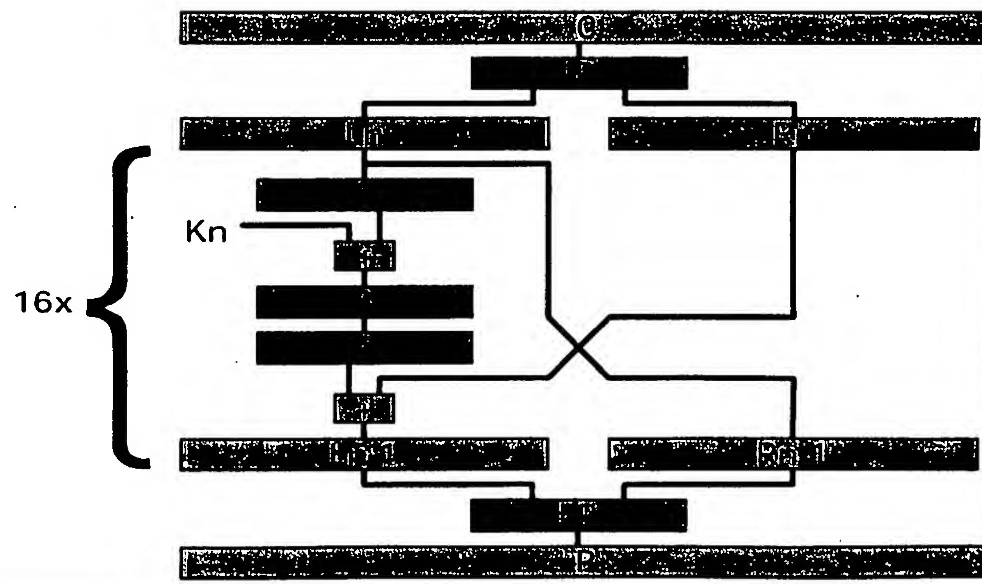


DES decryption

- CBC (Cypher Block Chaining) decrypt uses parallelism between blocks



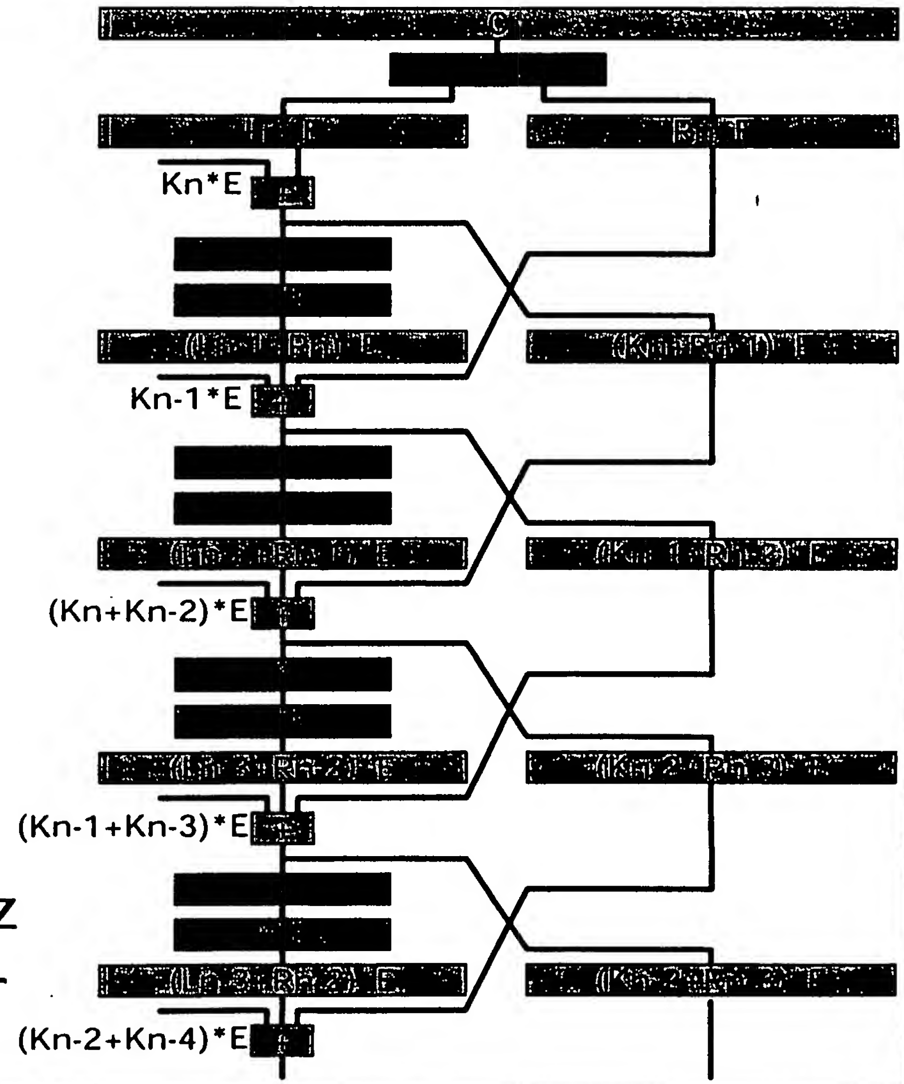
- DES decrypt
  - E expansion
  - + key xor
  - S substitution
  - P permutation
  - + data xor



Software DES

- **Optimizations**
  - 2 blocks/register
  - 4 blocks at once
  - distribute E
  - combine + +
- **Code**

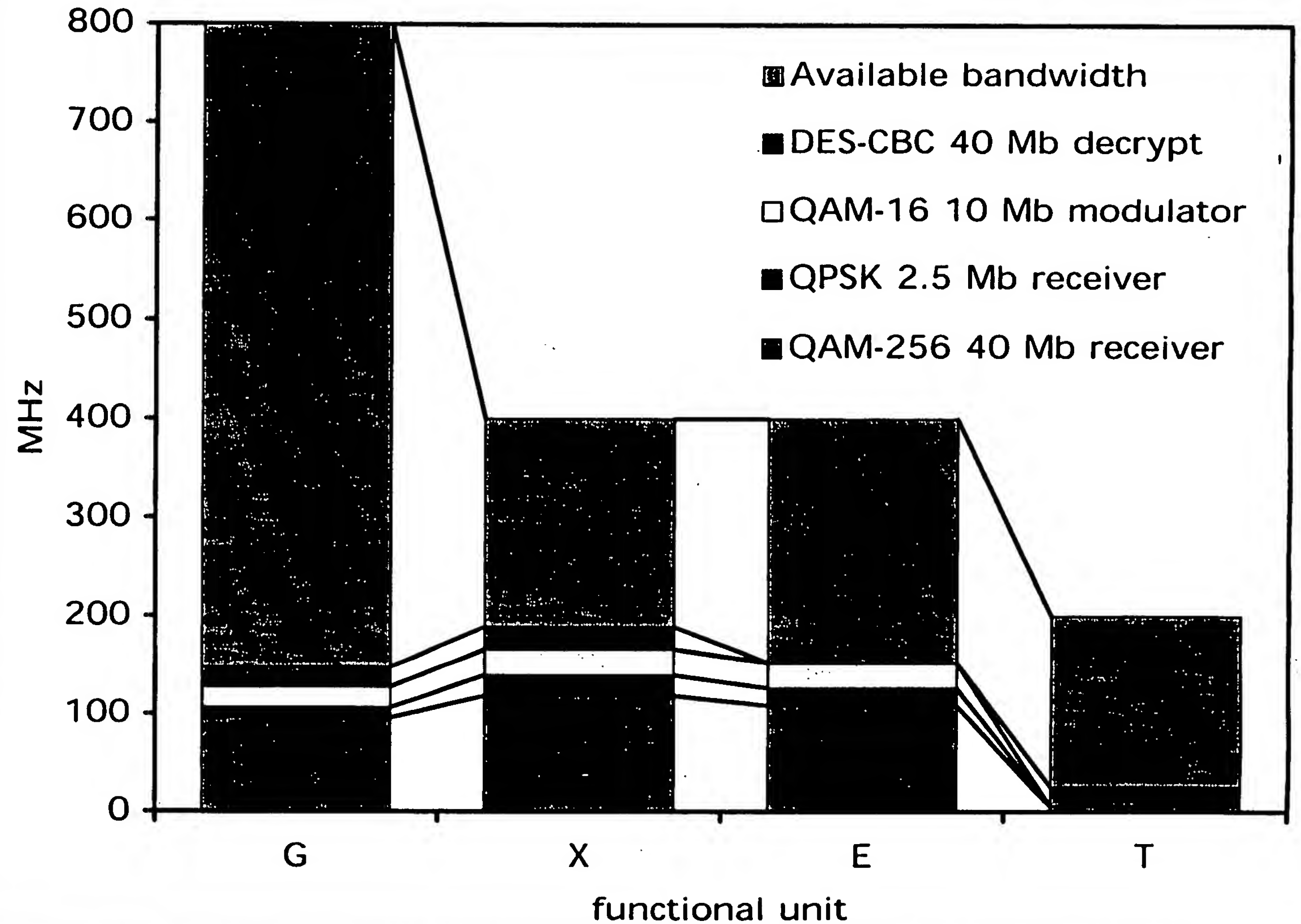
  K,+ L.128, G.XXX
  S W.TRANSLATE
  PE W.SWITCH
- **Performance**
  - 52 cycles/4 blocks
  - 985Mbps@200MHz
  - 10x per clock over fastest sw DES



Software DES

- DES standard at end of 20 year life
  - brute-force code-breaking
    - $10000 RSA DES Challenge
    - Electronic Frontier Foundation (EFF)
      - 56 hours to crack
      - $200k to <u>design and</u> build
  - FIPS standard expire this year
- Handles DES extensions
  - larger keys, bigger S-boxes
  - more rounds, larger blocks
  - soft S-boxes and P-boxes
- AES standard in development
  - 15 official candidates
  - new standard unpredictable

Instruction bandwidth for cable modem



Software tools

- Compiler-based development tools
  - C, C++ compiler
    - intrinsic functions, function inlining
    - register allocation, code scheduling
    - future: automatic parallelisation
  - object-module tools
    - linker, libraries, debugger
- OS: RT microkernel, Linux
- DSP libraries
- Sophisticated tools
    - Mathematica: symbolic verification
    - GOPS: cross-development library

Still to come

- Key code examples
  - signal
  - graphics
  - channel
- Architectural review
- Microarchitectural features
- Wide architecture